

Proposal for a Large Multipurpose Detector(LMD) at Homestake

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first phase: LMD-I

100kT or 200kT water Cherenkov, Fiducial:75-150kT

Participants in LOI for Homestake

- D. Cline, M. Diwan, K. Lande, R. Lanou, A.K. Mann, W. Marciano
- Speaking for many others. All are welcome.
- Close cooperation with UNO on the science.
- We advocate building one or two 100 kT cavities as soon as possible.

Outline of this talk

- Will focus on LMD-I, 100 kT water Cherenkov detector at Homestake
- Physics topics:
 - Very Long Baseline Neutrino Oscillation
 - Nucleon decay
 - Astrophysical neutrinos
- Brief details of study on accelerator beams.

Detector parameters

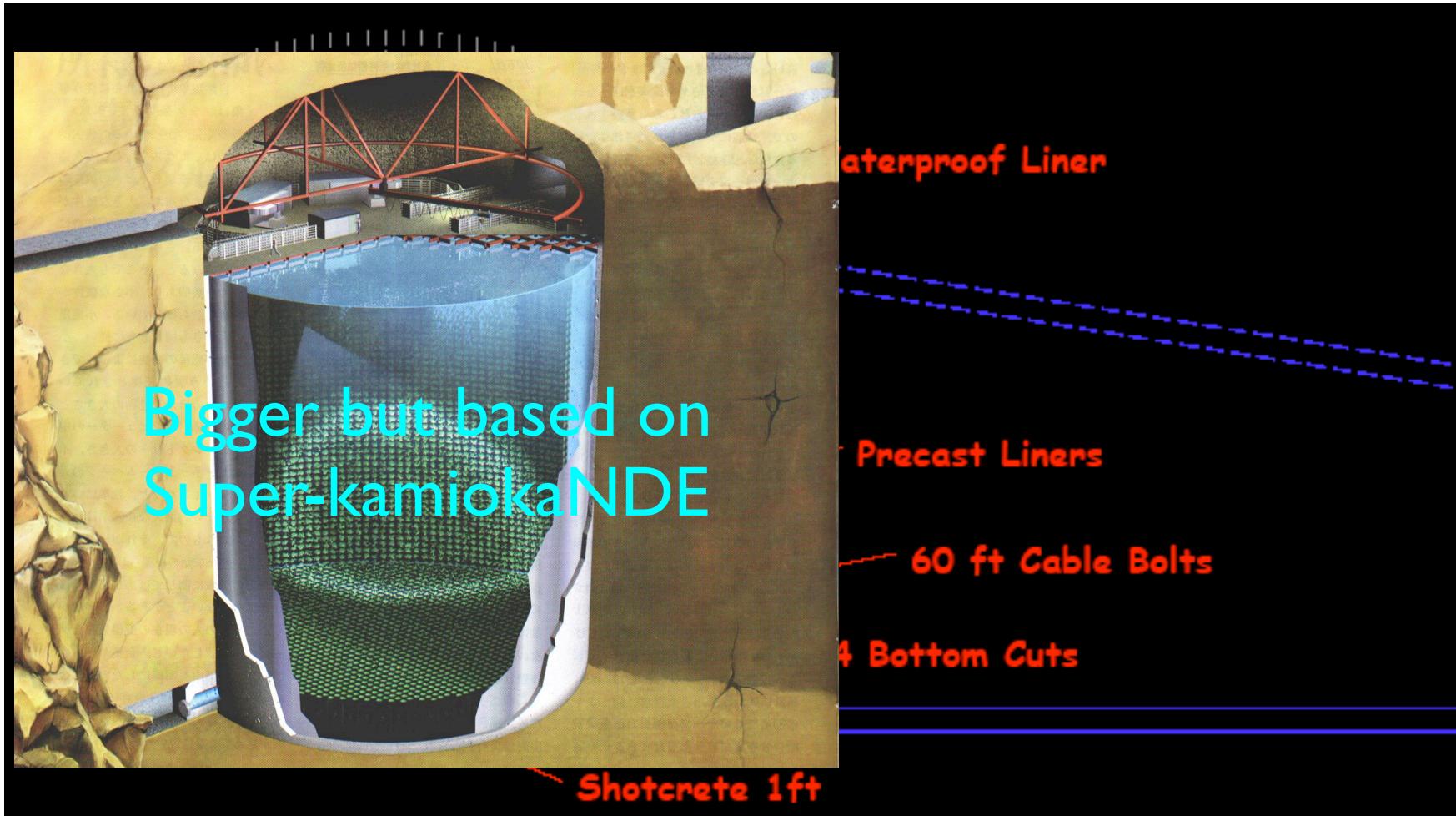
- Need 500 kT fiducial mass for proton decay, neutrino astrophysics.
- 100 kT is initial step => 50 m dia X 50 m high tank.
- depth ? May not need anti-counter if deep enough.
- ~10% energy resolution on quasileastics.
- Threshold of 5 MeV for solar and supernova
- Time res. ~few ns for pattern recognition.
- Good mu/e separation. <1%.
 - 1,2,3 track separation, NC rejection ~X20.

This level of performance can be obtained with water Cherenkov detector
with 20-40% PMT coverage.

=> 11000 to 22000 20inch PMTs for 100kT.

What does it look like

50 m diameter and 50 m tall



SuperKamiokaNDE: 22.5-50kT LMD-I: ~75-100kT

Cavity cost

✓ Estimated Costs For 1 Chamber (\$MM)

⇒ Labor & Benefits \$ 5.51

⇒ Mining & Construction

From	★ Equipment Operation	\$ 1.30
K. Lande	★ Supplies	\$ 4.51
and	★ Precast Concrete Liner	\$ 3.25
M. Laurenti		<hr/>
	Subtotal	\$ 9.06

⇒ Other (Outside Contractor) \$ 0.12

⇒ 15% Contingency \$ 2.20

TOTAL \$ 16.89
4 cavities for \$44 M

March 2002

208 weeks

could be accelerated

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Detector cost

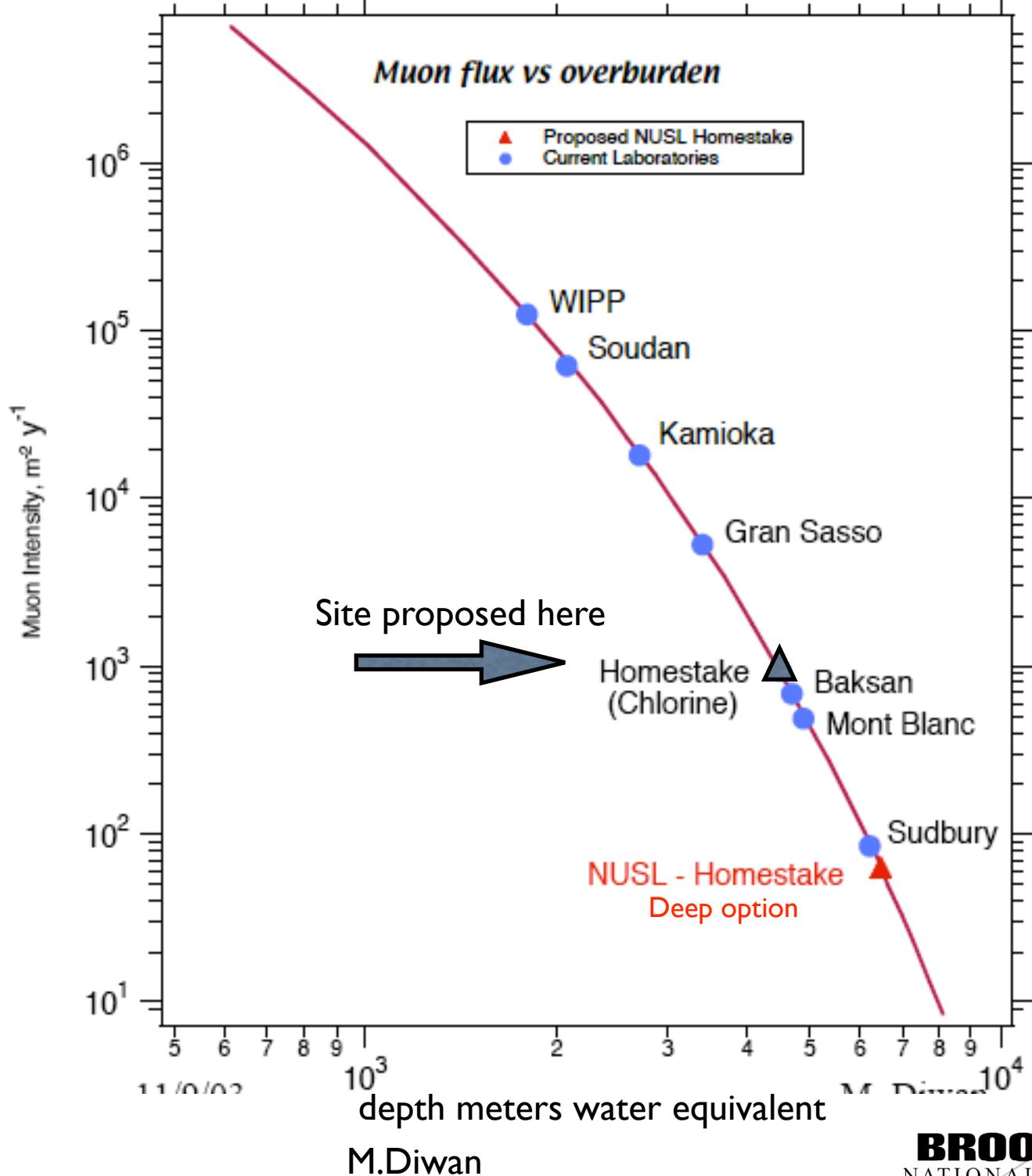
Excavation (including water liner) --	\$20 million
Photomultipliers (25% coverage)	
and electronics--	\$25 million
Water purification & handling	\$1 million
Miscellaneous	\$5 million
Contingency – (30%)	<u>\$16 million</u>
TOTAL	\$67 million

**4850ft:
100kT
~3M mu/yr**

with rate of 1 mu/10 sec => may not need veto-counter

The Beam neutrinos will be obvious with a rate of 100-200/day in 10 mus spills.

No pattern recognition beyond time cut is needed.

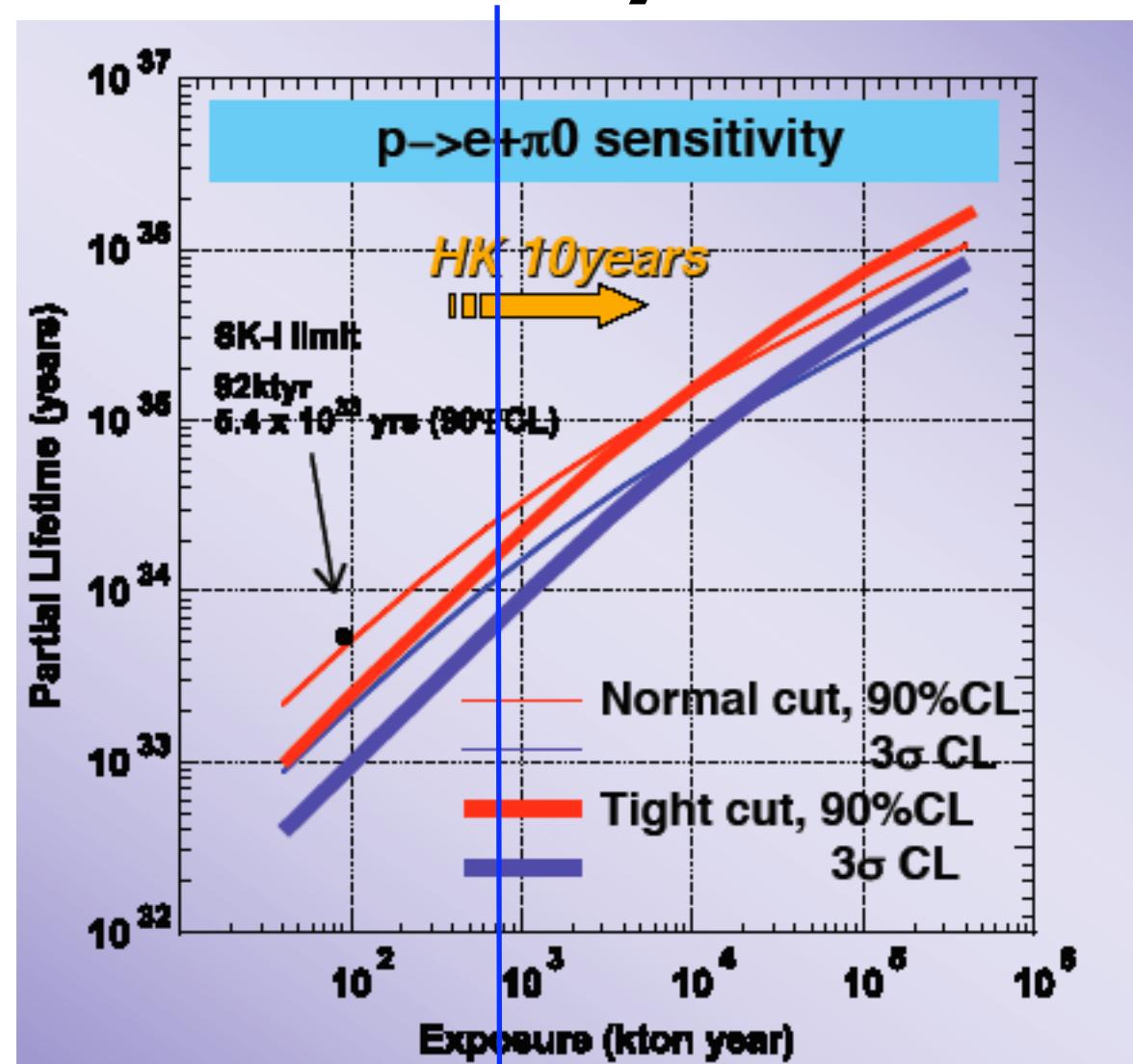


Open issues on detector

- Depth and veto counter - has cost, schedule and physics implications. Perhaps only the first module is built without veto-counter for a fast start.
- Fiducial volume. If SK cut good enough => 75 kT.
- PMT coverage: 20 % adequate from SK experience. 40% if very low threshold is needed.
- PMT size: 13 inch versus 20 inch. Greater number of pixels will give better pattern recognition.
- Size of detector: very difficult to increase span. If made bigger has cost and schedule implications. 50 meter span seems adequate to contain beam events.

Nucleon decay

- Large body of work by HyperK, and UNO.
- background levels for the positron+Pion mode
 - $3.6/\text{MTon-yr}$ (normal)
 - $0.15/\text{MTon-yr}$ (tight)
- LMD-I(100kT) will hit backg. in ~ 3 yrs. It could be important to perform this first step before building bigger.
Sensitivity on K-nu mode is about $5 \times 10^{33} \text{ yr}$



Ref: Shiozawa (NNN05)

LMD-I X 10 yrs $3 \times 10^{34} \text{ yrs}$

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Astrophysical Neutrinos

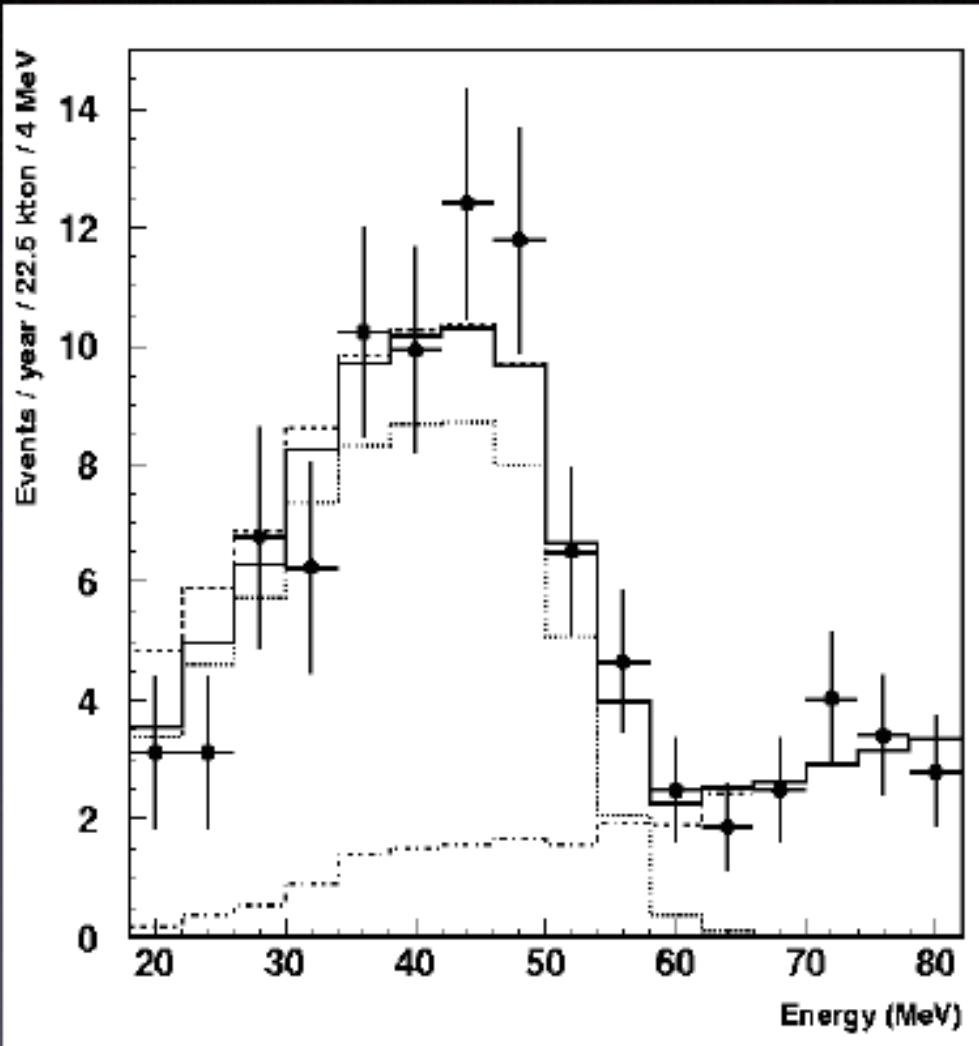
Event rates. LMD-I(100kT), assume 5 yrs

- Atmospheric Nus: ~10000 muon, ~5000 electrons. (Ref: Kajita nnn05)
- Solar Nus: >63000 elastic scattering $E>5\text{MeV}$ (including Osc.) (Ref: uno)
- Galactic Supernova: ~30000/10 sec in all channels. (~1000 elastic events). (Ref: uno)
- Relic Supernova: (ref: Ando nnn05)
 - flux: $\sim 5 \text{ (1.1) } /cm^2/\text{sec} \text{ Enu}>10 \text{ (19) MeV}$
 - rate: 75 (35) events over backg ~ 100 !

Need analysis with these numbers

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Observational Result by Super-K



Malek et al. 2003

- Analysis using data for 1496 days (4.1 yr).
- As the result, they could not find positive signal.
- Upper limit on the SRN flux ($E_\nu > 19.3$ MeV):

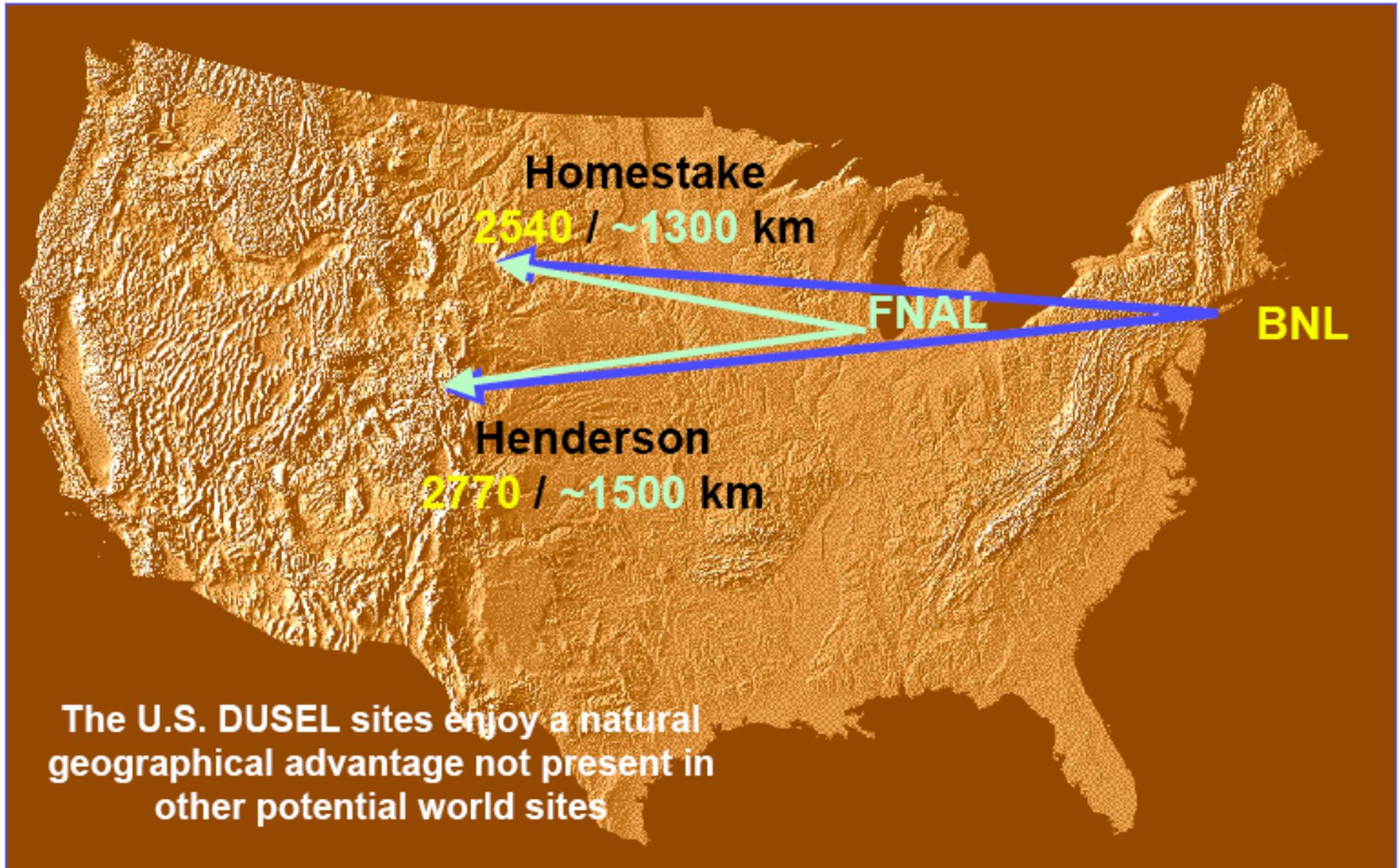
$$1.2 \text{ cm}^{-2} \text{ s}^{-1}$$

(90% C.L.)

Just above the prediction
($1.1 \text{ cm}^{-2} \text{ s}^{-1}$)

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Super Neutrino Beam to DUSEL Candidate Sites



Why Very Long Baseline?

observe multiple nodes
in oscillation pattern

☞ less dependent
on flux normalization

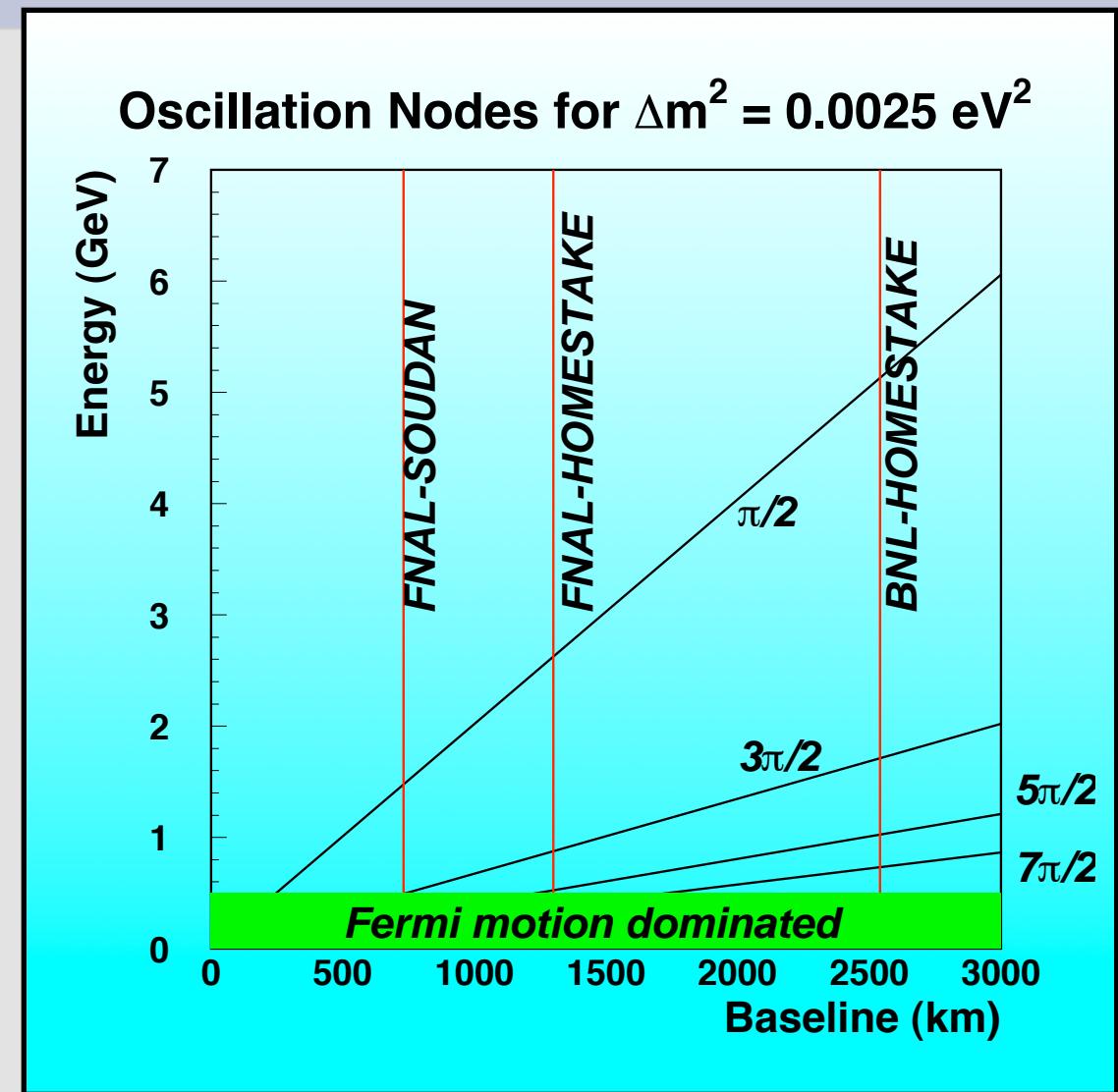
neutrino travels larger
distance through earth

larger matter effects

flux $\sim L^{-2}$: lower statistics
but: CP asymmetry $\sim L$

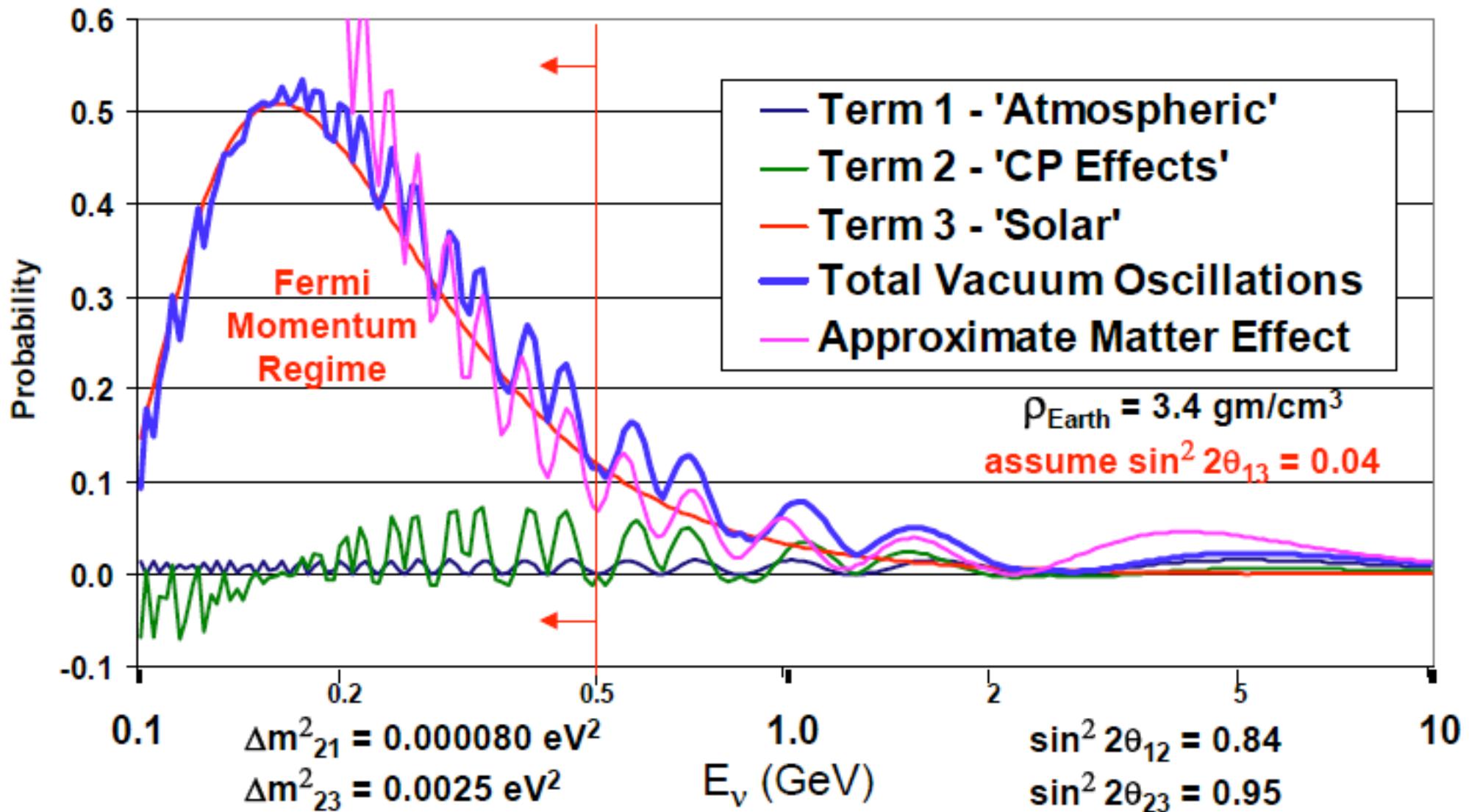
sensitivity to δ_{CP} independent of distance!

better S:B



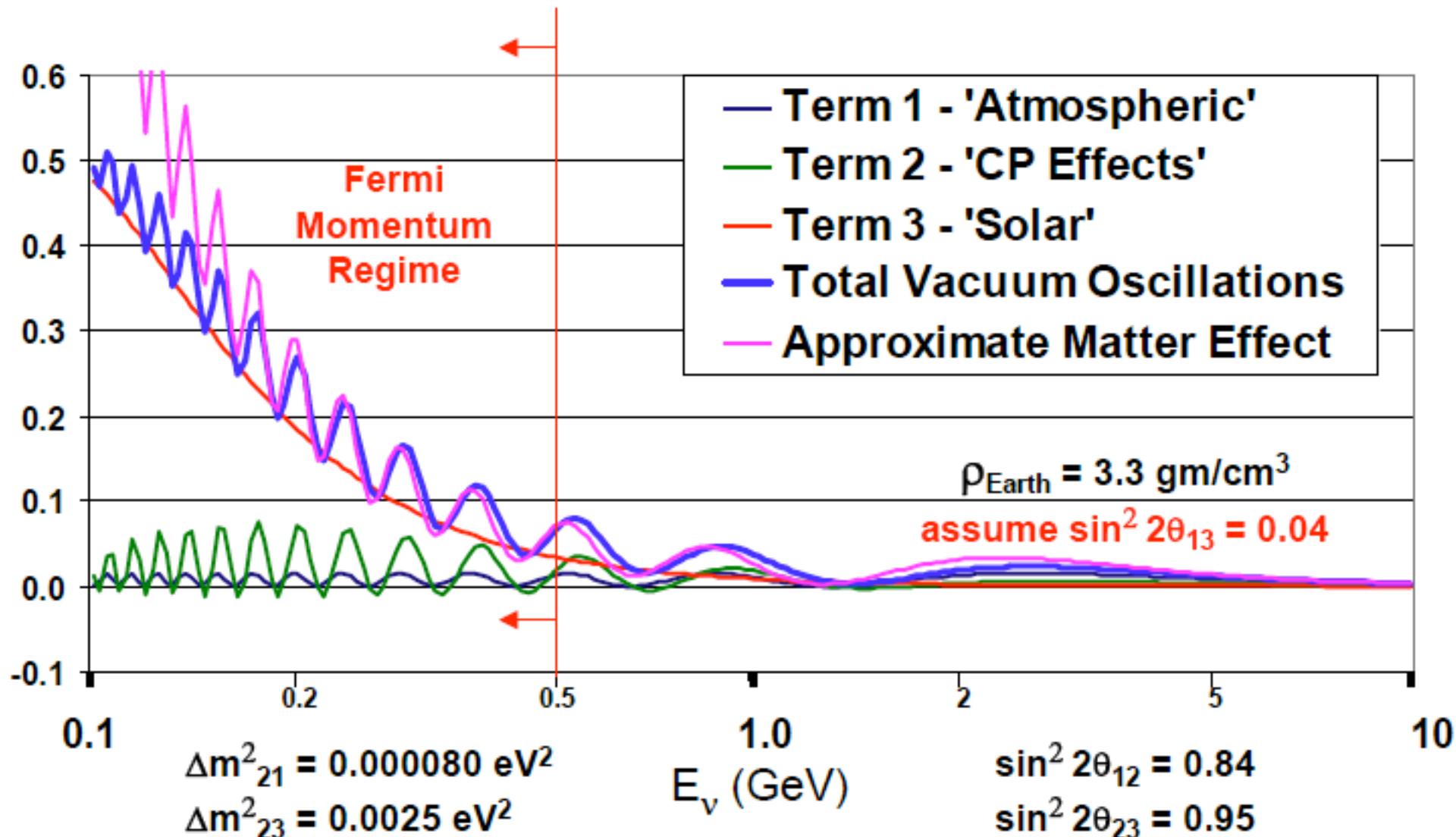
(Marciano hep-ph/0108181)

$\nu_\mu \rightarrow \nu_e$ Vacuum Oscillations - VLBNO
 $L = 2540$ km – BNL to Homestake



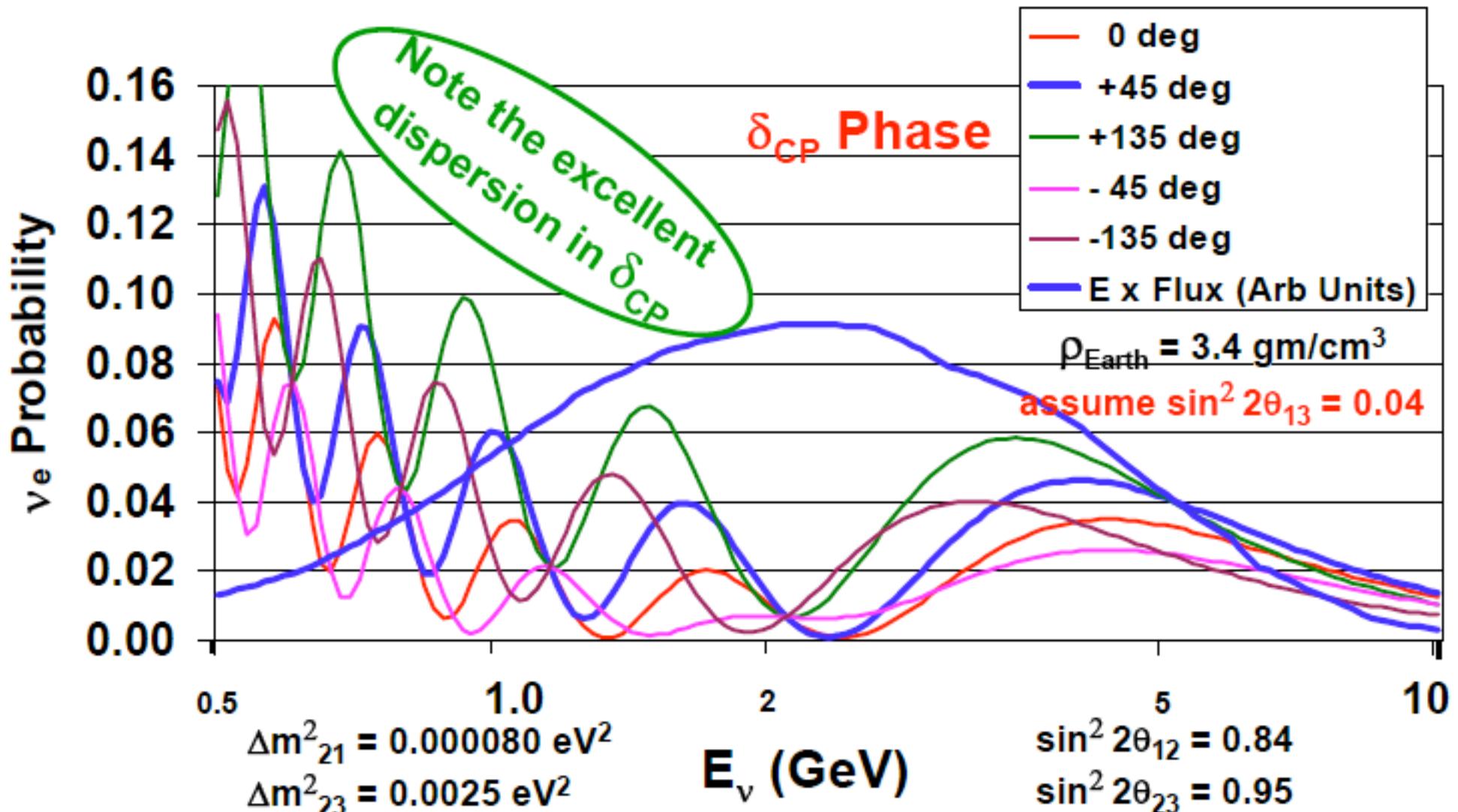
$\nu_\mu \rightarrow \nu_e$ Vacuum Oscill. - VLBNO

L = 1300 km – FNAL to Homestake



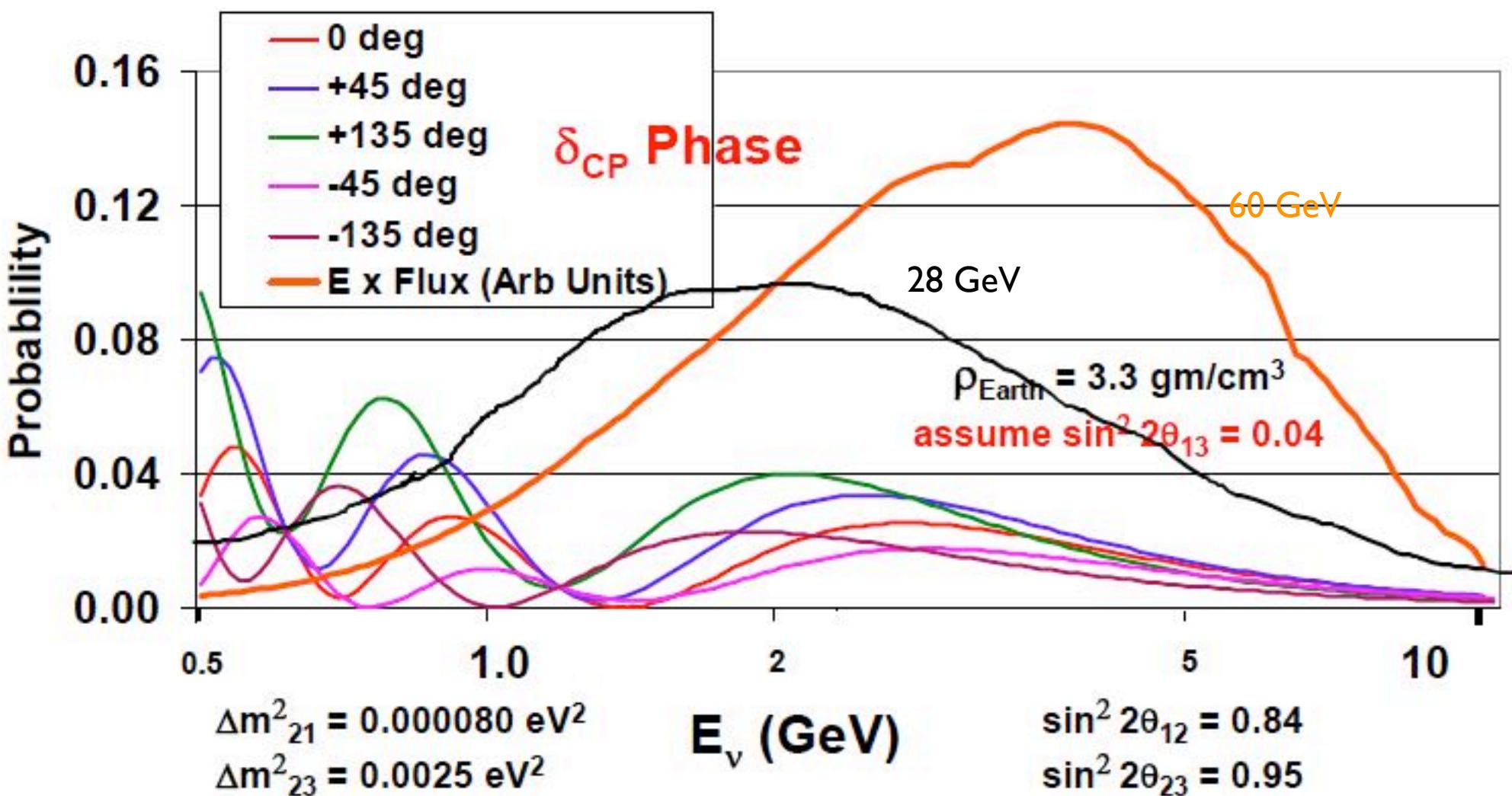
$\nu_\mu \rightarrow \nu_e$ CP Phase Effects - VLBNO

$L = 2540$ km – BNL to Homestake



$\nu_\mu \rightarrow \nu_e$ CP Phase Effects - VLBNO

L = 1300 km – FNAL to Homestake



Important points

- Sensitivity to CP is independent of distance! (see P. Huber's calculation)
- The size of detectors and beam power needed does not depend on theta_I3 (as long as it is not very small)
- We need low energy broad band beam. Must have ~4m wide tunnel. I have assumed 200 m length. Low energy horn also (with target deep inside)

US possibilities for beam

Source	Proton beam energy	Proton beam power
FNAL MI (McGinnis upgrade)	$E_p = 8-120\text{ GeV}$	$1-2 \text{ MW} \propto (E_p/120\text{ GeV})$
FNAL MI (with 8GeV LINAC)	$E_p = 8-120 \text{ GeV}$	2 MW @ any E_p
BNL-AGS (upgrade 2.5- 5 Hz)	$E_p = 28 \text{ GeV}$	1-2 MW

US possible baselines

Source	Detector	Distance	Depth	Comment
FNAL	Homestake	1290 km	4850/ 7700ft	no beam, DUSEL site, capable of large exca.
FNAL	Henderson	1500km	~4000 ft	no beam, DUSEL site, capable of large exca.
BNL	Homestake	2540km	4850/ 7700 ft	study of beam and physics exists and documented
BNL	Hendersn	2767km	~4000 ft	--

shorter baseline means more events.
longer baseline means bigger effects.

Neutrino Event rates

Source-det	Detector size	beam E and power	Event rate for neutrino running
FNAL-HS(1290)	100kT	0.5MW@60GeV	~30,000CC ~10,000NC
FNAL-Hend(1500)	100kT	0.5MW@60GeV	~22,000 ~7500
FNAL-HS(1290)	100kT	2MW@28GeV	78,000CC 27,000NC
FNAL-HS(1290)	100kT	2MW@8GeV using Miniboone data	1094 CC 425 NC
NOVA(810)*	30kT	0.65MW@120	~10000 CC ~3000 NC

5×10^7 sec of running assumed

*rescaled: NOvA assumes 2×10^7 sec * 5 yrs of running in their proposal

How to achieve the total exposure

- For CP violation we need (indep. of baseline or size of theta_13) (Marciano)
- $2500 \text{ kT} * \text{MW} * (10^7) \text{ sec}$ for neutrinos

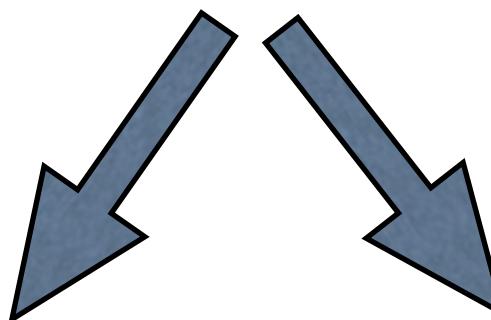
1 yr $\sim 1 \text{e}7 \text{ sec}$

500kT

1 MW

5 yrs

Past approach



1 yr $\sim 2 \cdot 10^7 \text{ sec}$

100kT

2 MW

6.25 yrs

We could go to
200 kT if only
1 MW

Possible at FNAL with
new Proton driver

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ν_e Appearance

Backgrounds

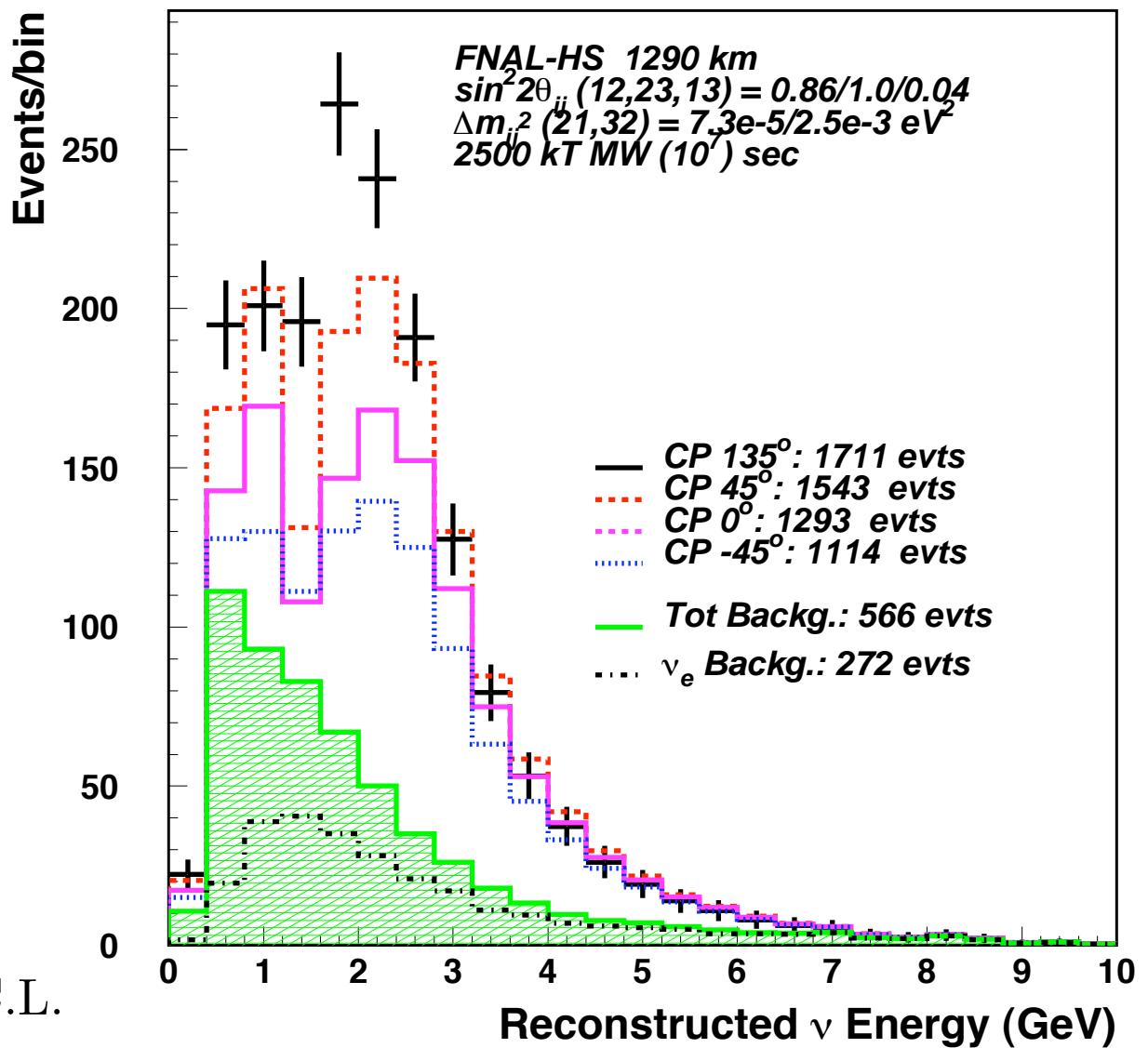
- beam ν_e
- Neutral current events

ν running

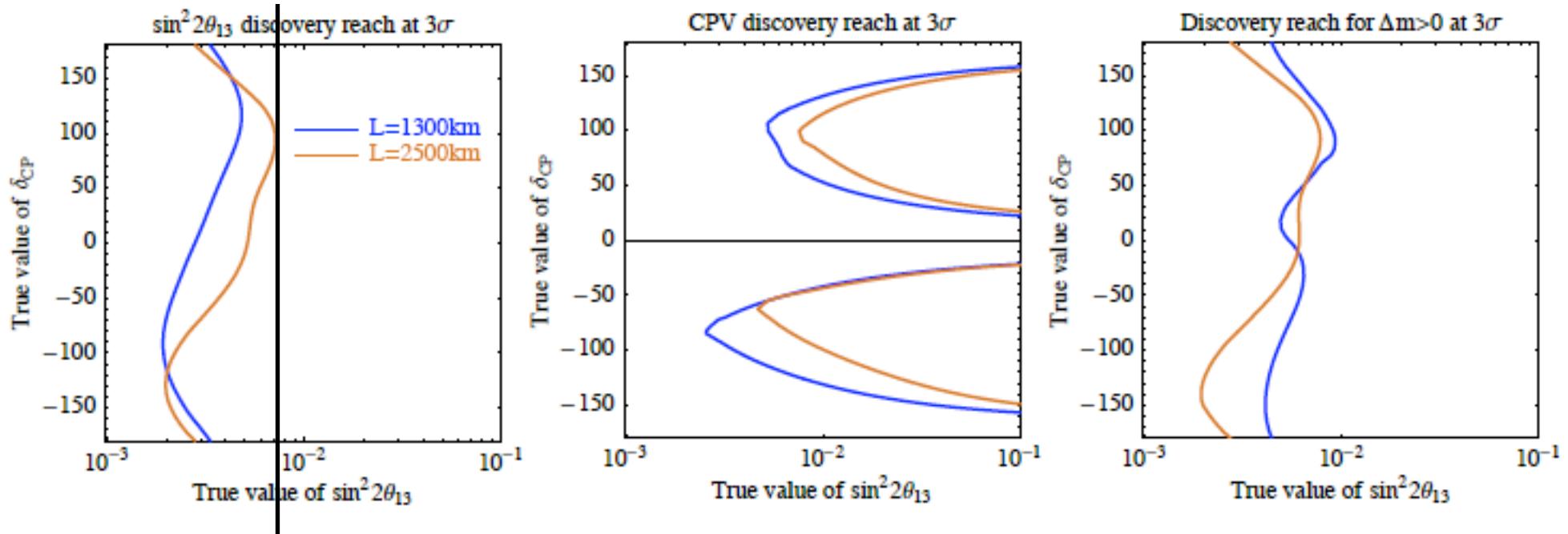
- measure $\sin^2 2\theta_{13}$ and δ_{CP} .
- resolve mass hierarchy for $\sin^2 2\theta_{13} > 0.01$
- with $\bar{\nu}$ running
 $\sin^2 2\theta_{13} > 0.003$ at 90% C.L.

If $\sin^2 2\theta_{13}$ too small δ_{CP} cannot be measured. (See Patrick's curves).

ν_e APPEARANCE



Wide band beam

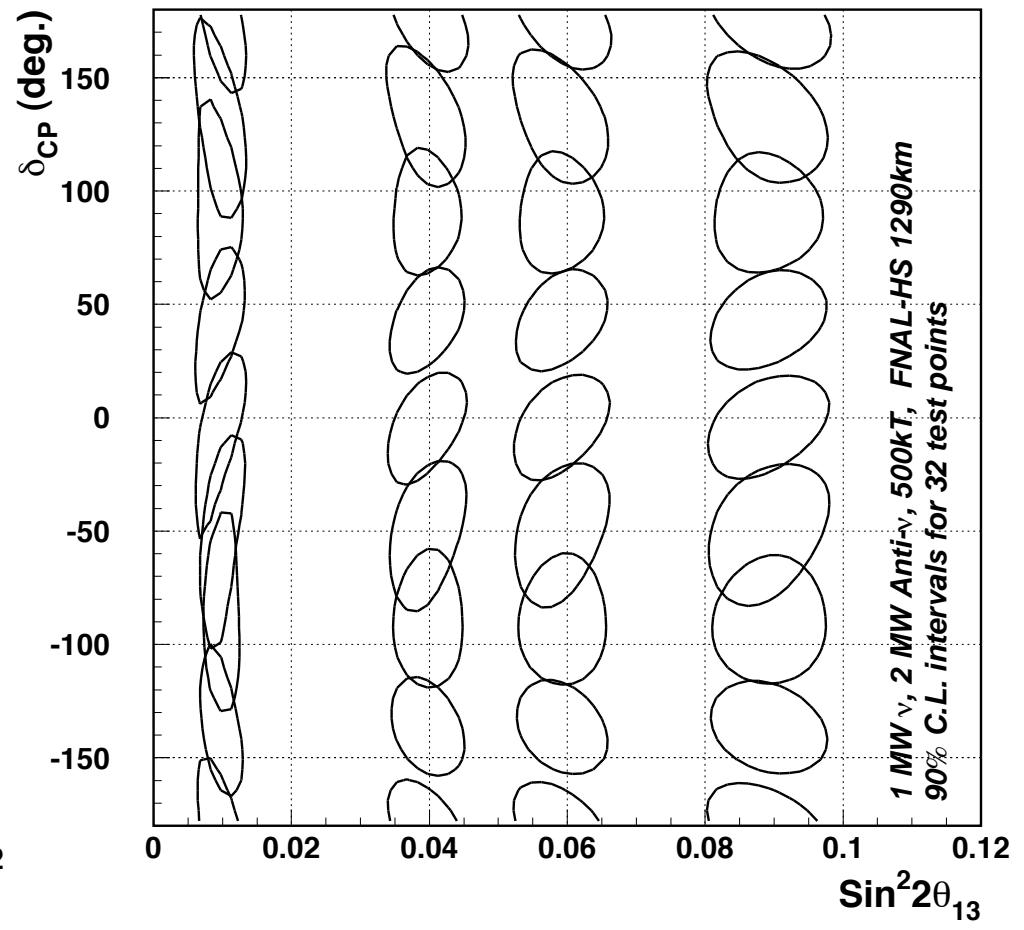
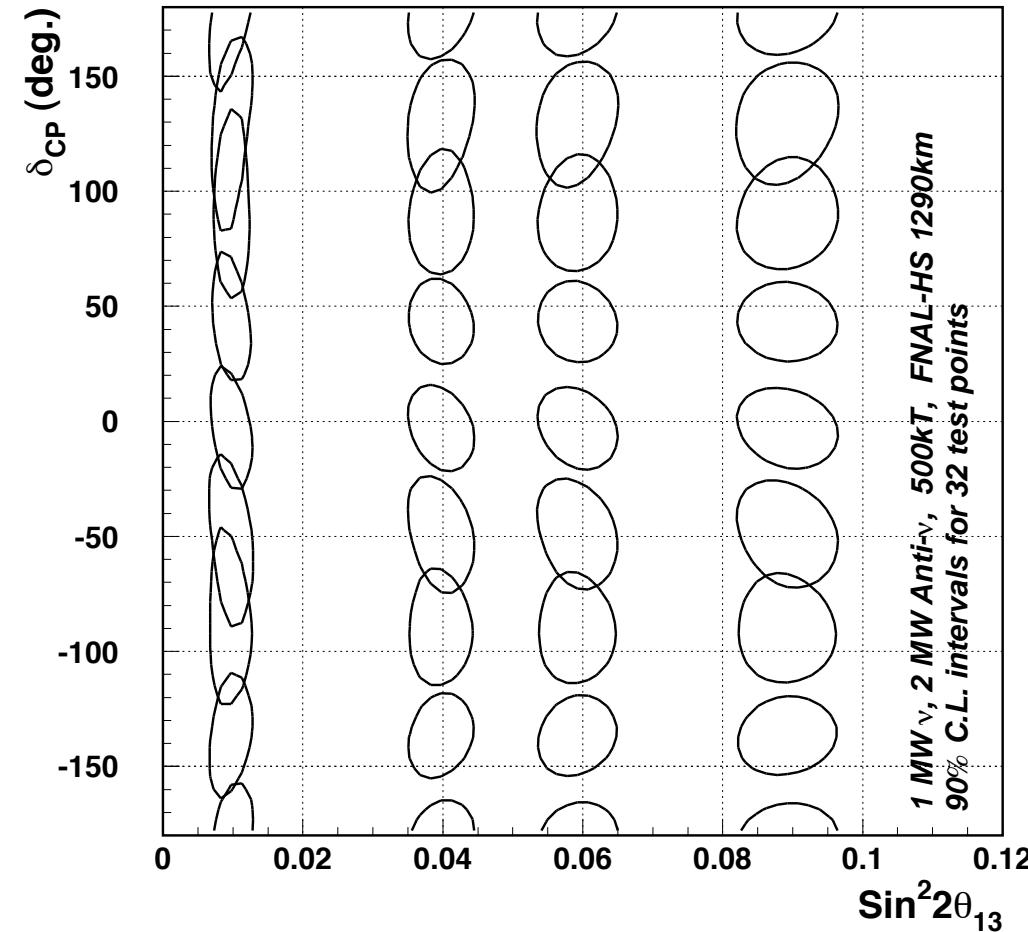


- very good resolution of the mass hierarchy
- no problems due to π -transit for $\sin \delta > 0$
- Baseline choice is not critical

includes anti running, but large fraction of the result is from nu running for normal hierarchy

We prefer to think of CP as a parameter measurement

Regular hierarchy ν and Anti ν running Reversed hierarchy ν and Anti ν running



ν_μ Disappearance

Neutrino Running

- Total exposure: 2500 kT.MW.(10^7).sec
- 195000 CC evts/6yrs: 2MW-FNAL, 100kT-HS
- Use only clean single muon events.

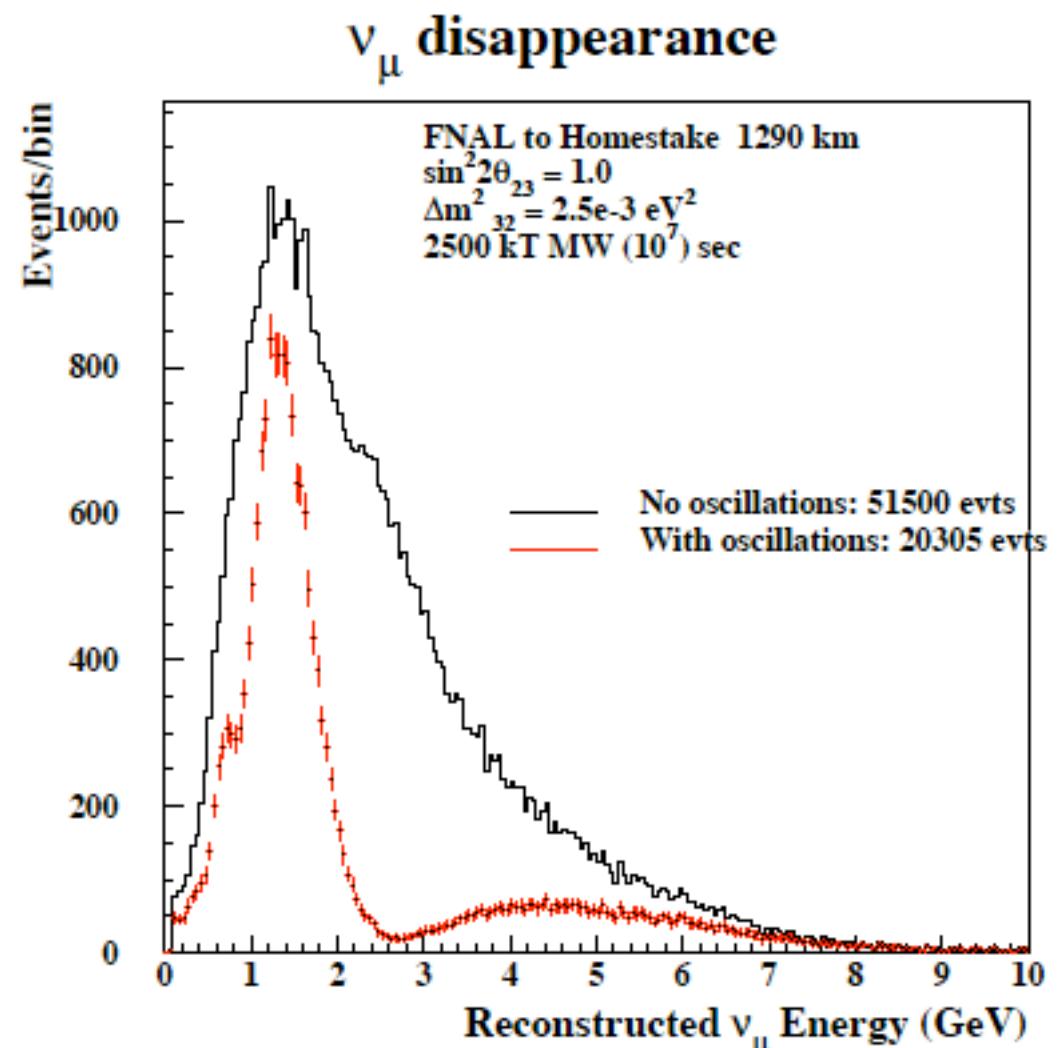
Measurements

- 1% determination of Δm_{32}^2
- 1% determination of $\sin^2 2\theta_{23}$
- Most likely systematics limited.

$\bar{\nu}$ running

- Need twice the exposure for similar size data set.
- very precise CPT test possible.

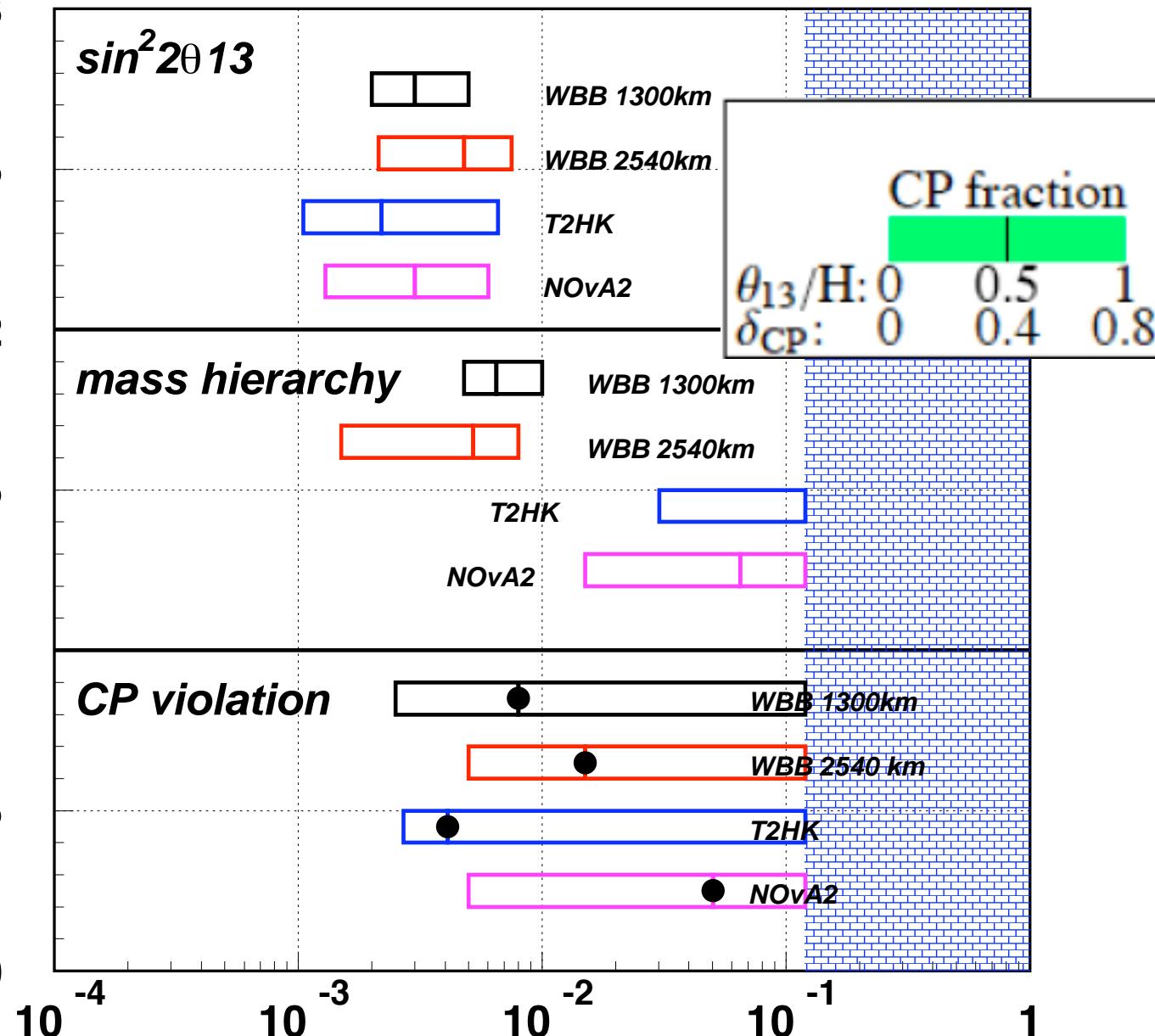
Very easy to get this effect
Does not need extensive pattern recognition. Can enhance the second minimum by background subtraction.



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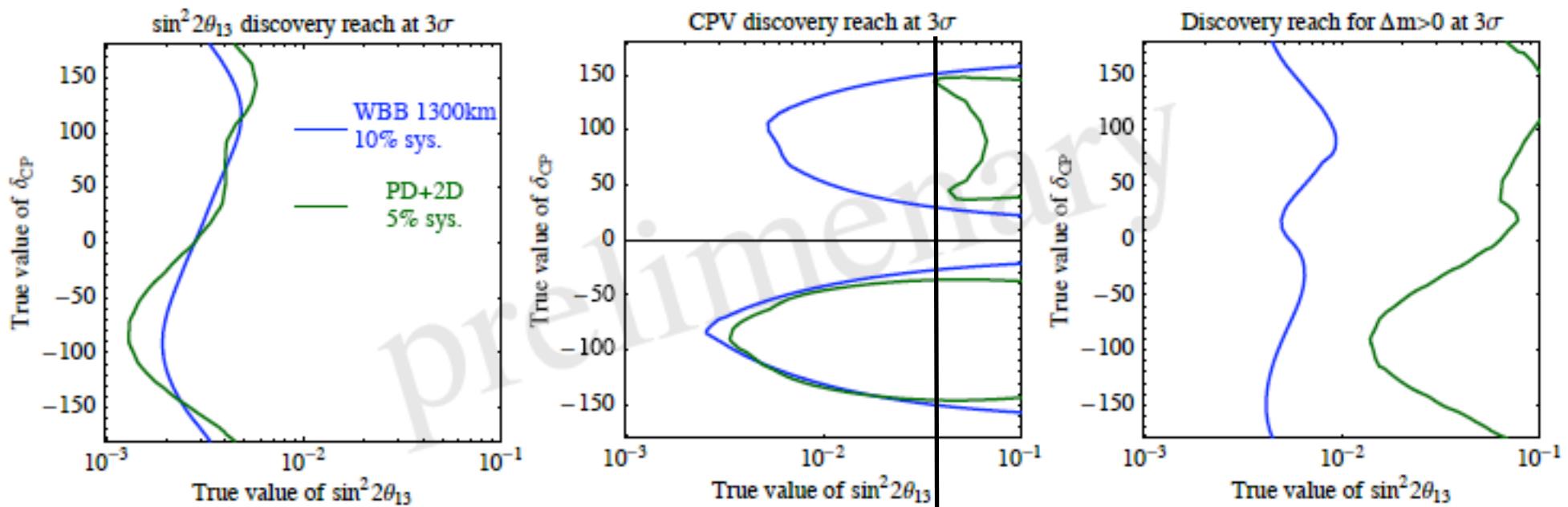
Comparison of 3σ reach

Assumptions



- **WBB:**
 nu: $100kT \cdot 2MW \cdot 6yr$.
 antinu: $100kT \cdot 2MW \cdot 6yr$
 syst: 10% on bck
 Antinu running is over-constraint for normal hierarchy.
- **T2HK:**
 nu: $1000 kT \cdot 4MW \cdot 3yr$
 antinu: $1000 kT \cdot 4MW \cdot 3yr$
 syst: 2% on bck
- **NOV2:**
 nu: $30kT \cdot 2MW \cdot 6yr + 80kT \cdot 2MW \cdot 3yr$
 antinu: same $\cdot 6yr + 3yr$
 syst: 5% on bck

Summary



How would that picture look like with

- Liquid Argon
- 2nd peak in the OA spectrum

Open issues on beam

- What is the correct proton energy and power level from FNAL
- What is the cost of a new beam
- To get intensity at low energies must have ~4 meters diameter tunnel. I have length of 200 meters to get the spectra in this talk.
- How should we tailor the spectrum for maximum signal/noise ?
- If tunnel is wide WE CAN ALWAYS RUN OFFAXIS by moving and tilting the horn/target. (upto 1 deg.)
- What is the time sequence ? Proposal on next slide.

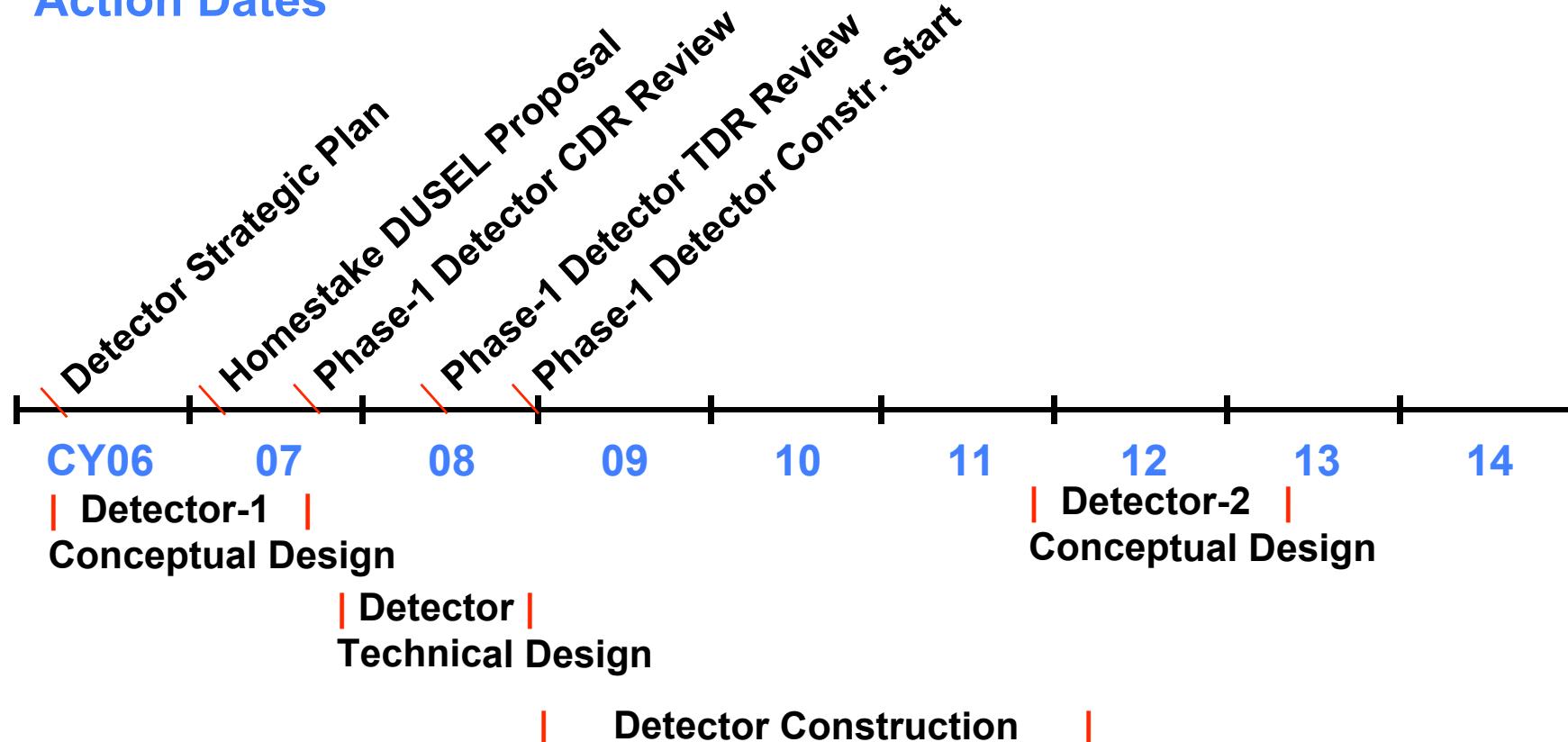
Summary

- Physics case for a 100 kT detector at Homestake.
- nucleon decay, astrophysical neutrinos, long baseline.
- Lowest risk most cost effective option for a long baseline second generation experiment.
- Money ? It will cost money, but time and scientific manpower issues more important.
- Possible time sequence:
 - 100 kT + 0.5 MW (60GeV)=> 68 evts/day
 - 200 kT + 1 MW (30GeV) => 180 evts/day
 - 200 kT + 2 MW (30 GeV)=> 360 evts/day

EXTRAS

Homestake VLBNO Program Timeline

Action Dates



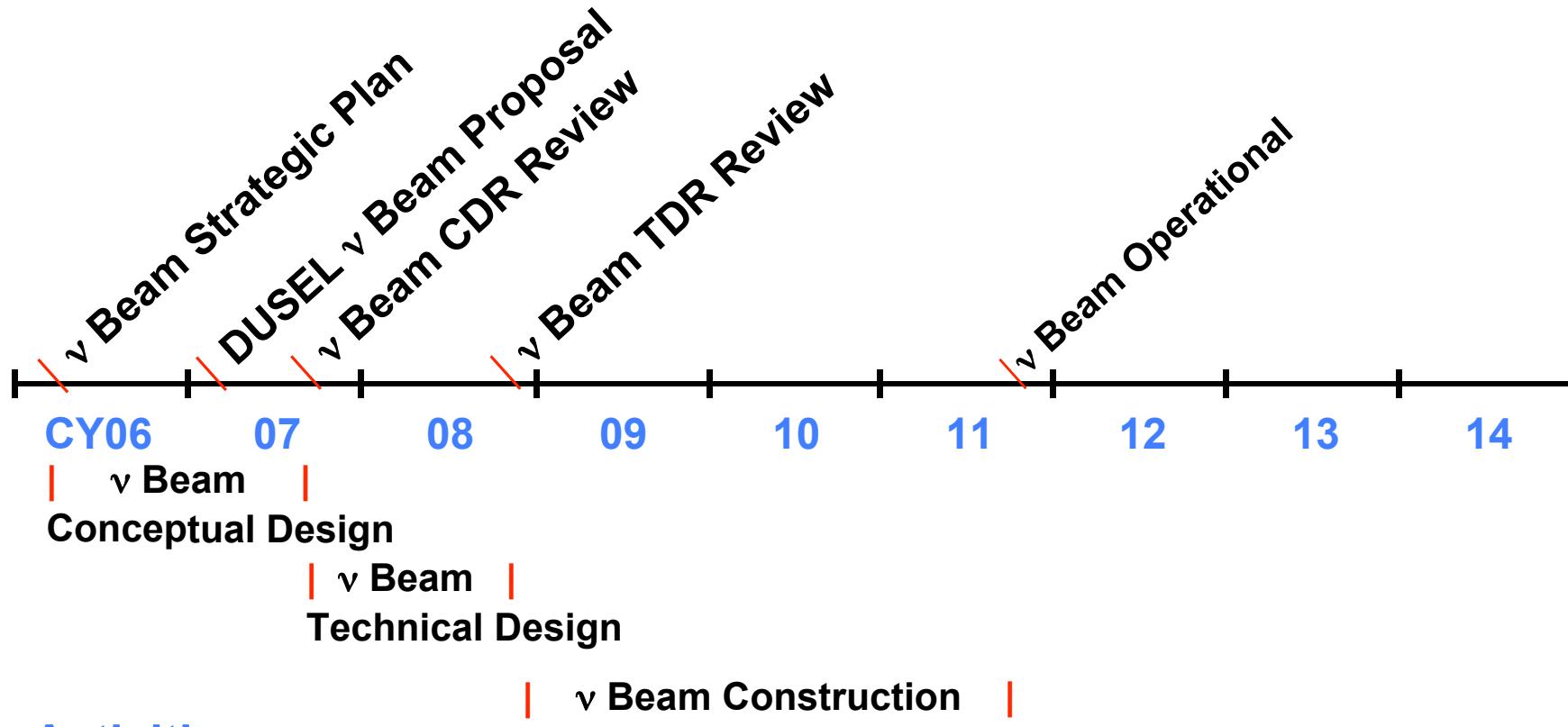
Activities

from T. Kirk

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ν Beam Accelerator Program Timeline

Action Dates



Activities

from T. Kirk

Electron neutrino appearance physics parameter extraction

For 1000 - 2000 km baseline
effects across energy band.

	$E_\nu < 1 \text{ GeV}$	$1 < E_\nu < 2 \text{ GeV}$	$E_\nu > 2 \text{ GeV}$
$\sin^2 2\theta_{13}$	✓	✓	✓
$\text{sign}(\Delta m_{32}^2)$	-	-	✓✓✓
δ_{CP}	✓	✓✓	✓
solar	✓✓✓	✓	-

- It's a complex picture with many effects!
- But, effects have different strength at different energies.
- Measuring across the wide energy band makes it possible to sort them out.

What about anti-nu running

- Depends on mass hierarchy.
- To be completely risk-free need
 - $5000 \text{ kT} * \text{MW} * (10^7) \text{ sec}$

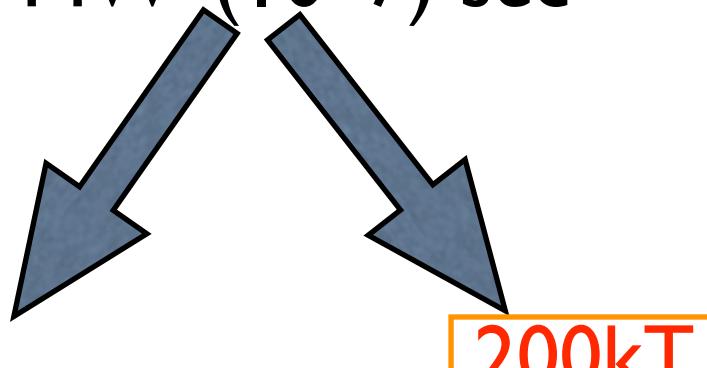
$1 \text{ yr} \sim 1e7 \text{ sec}$

500kT

2 MW

5 yrs

Past approach



$1 \text{ yr} \sim 2e7 \text{ sec}$

200kT

2 MW

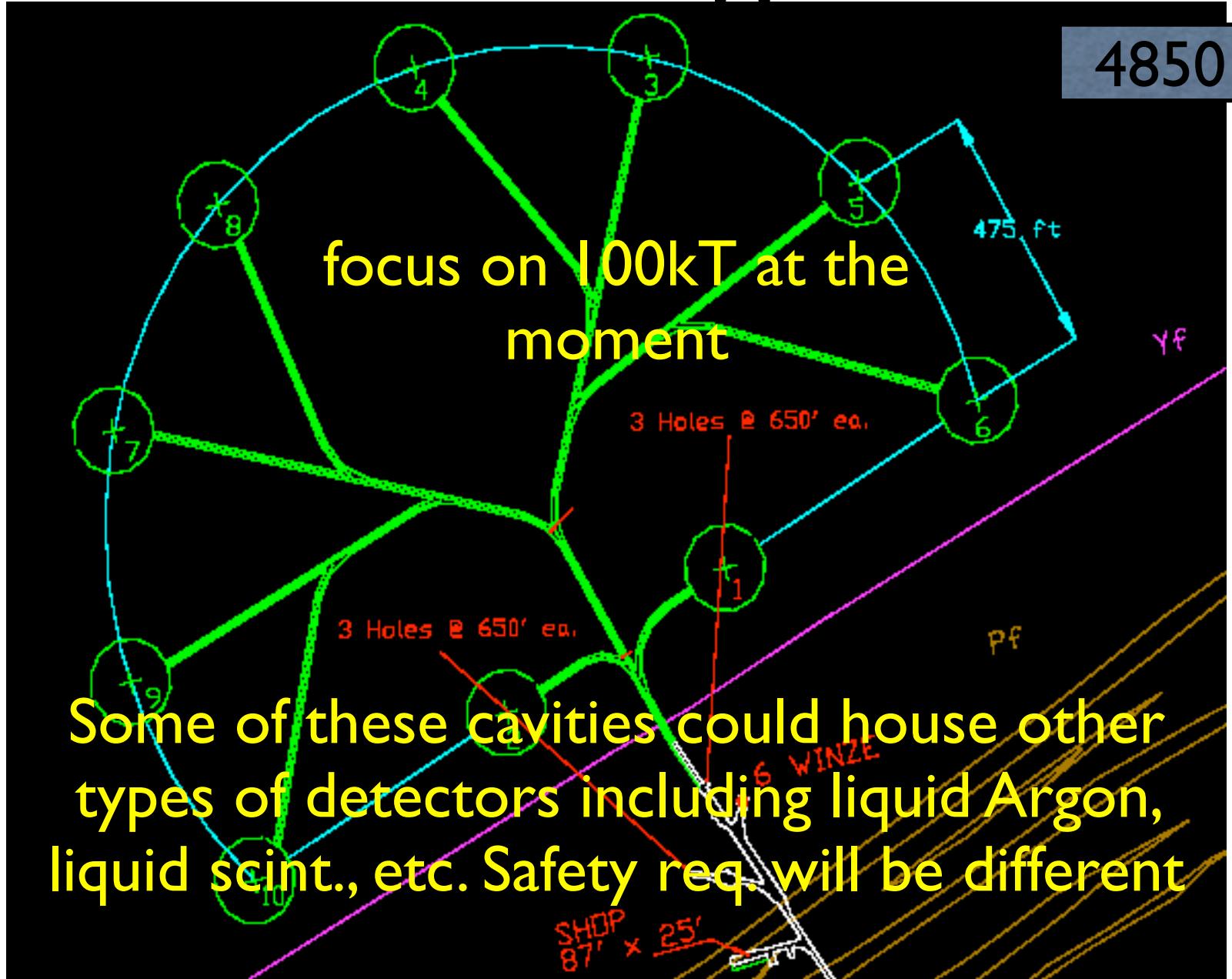
6.25 yrs

Possible at FNAL with
new Proton Driver

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We want to grow to..

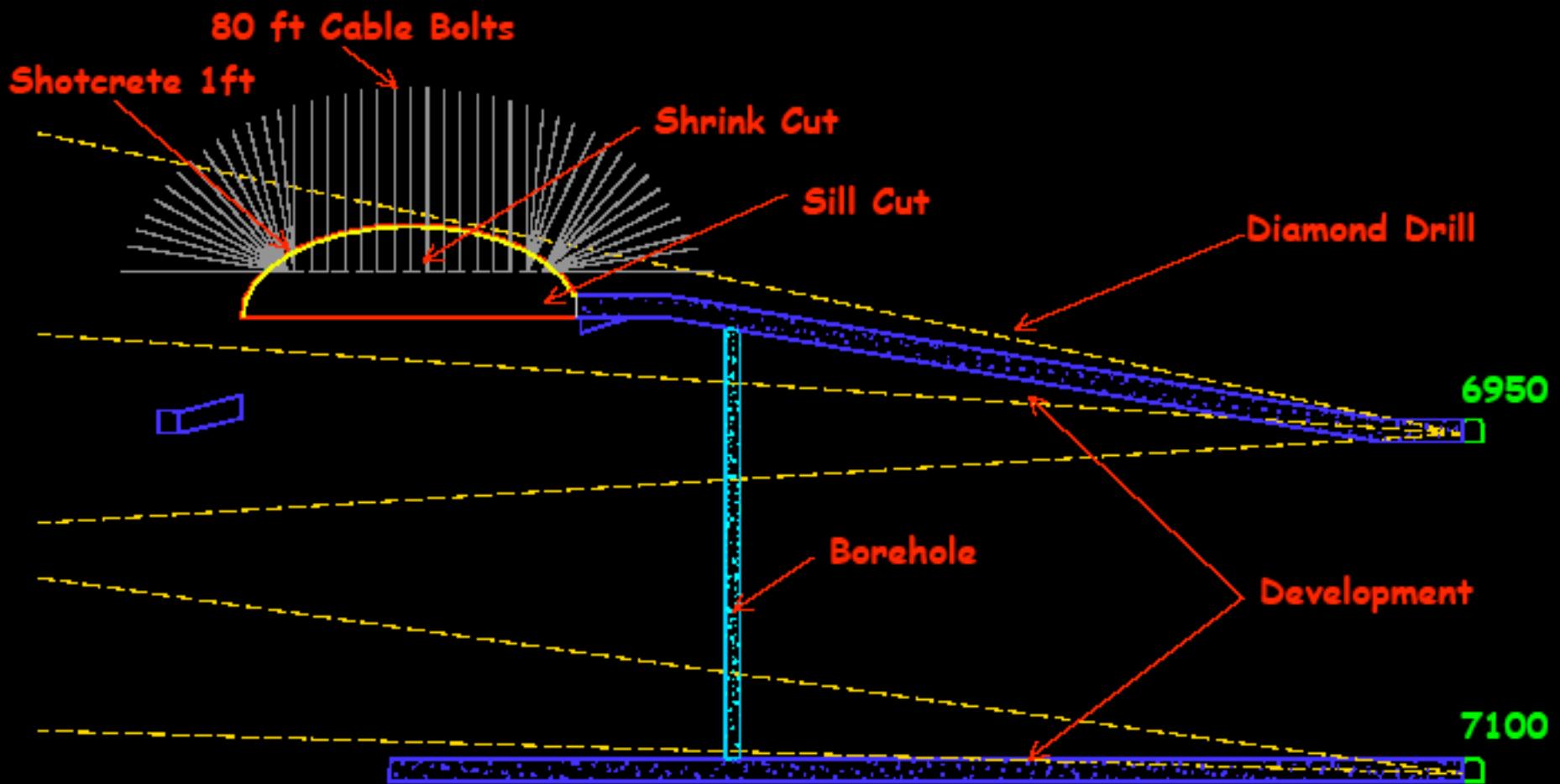
4850



How to build it..

✓ Estimated Timeline

Year One

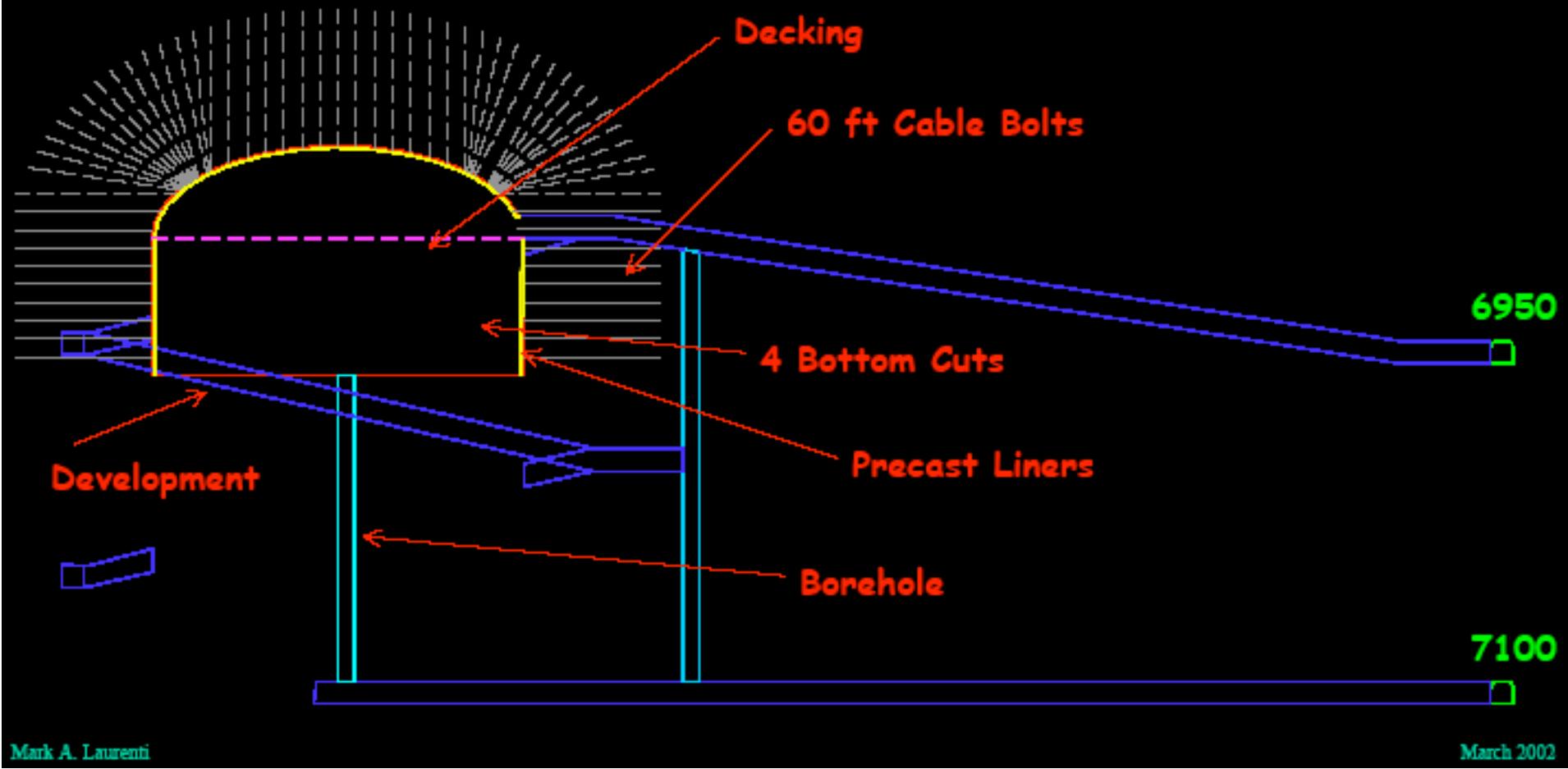


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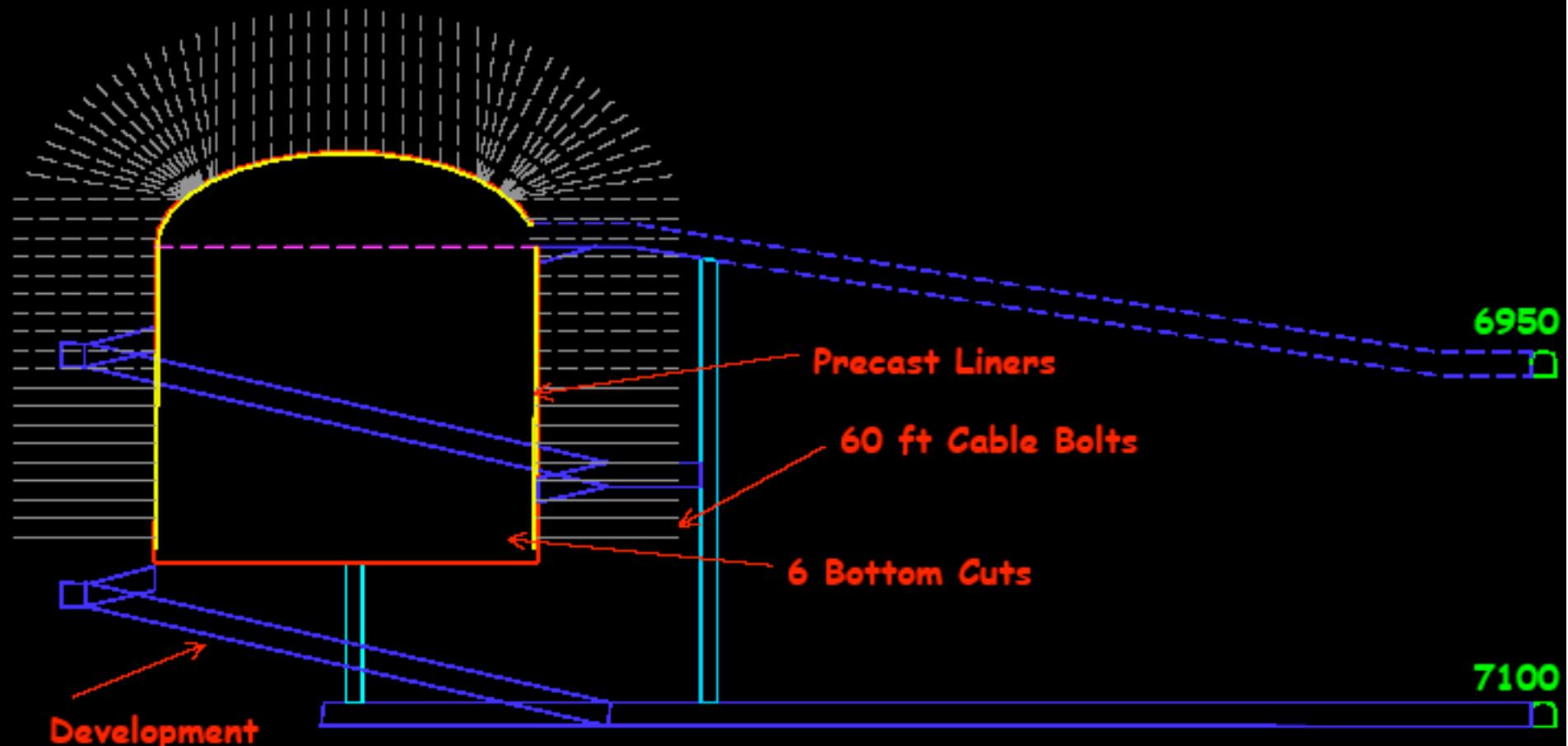
✓ Estimated Timeline

Year Two



✓ Estimated Timeline

Year Three

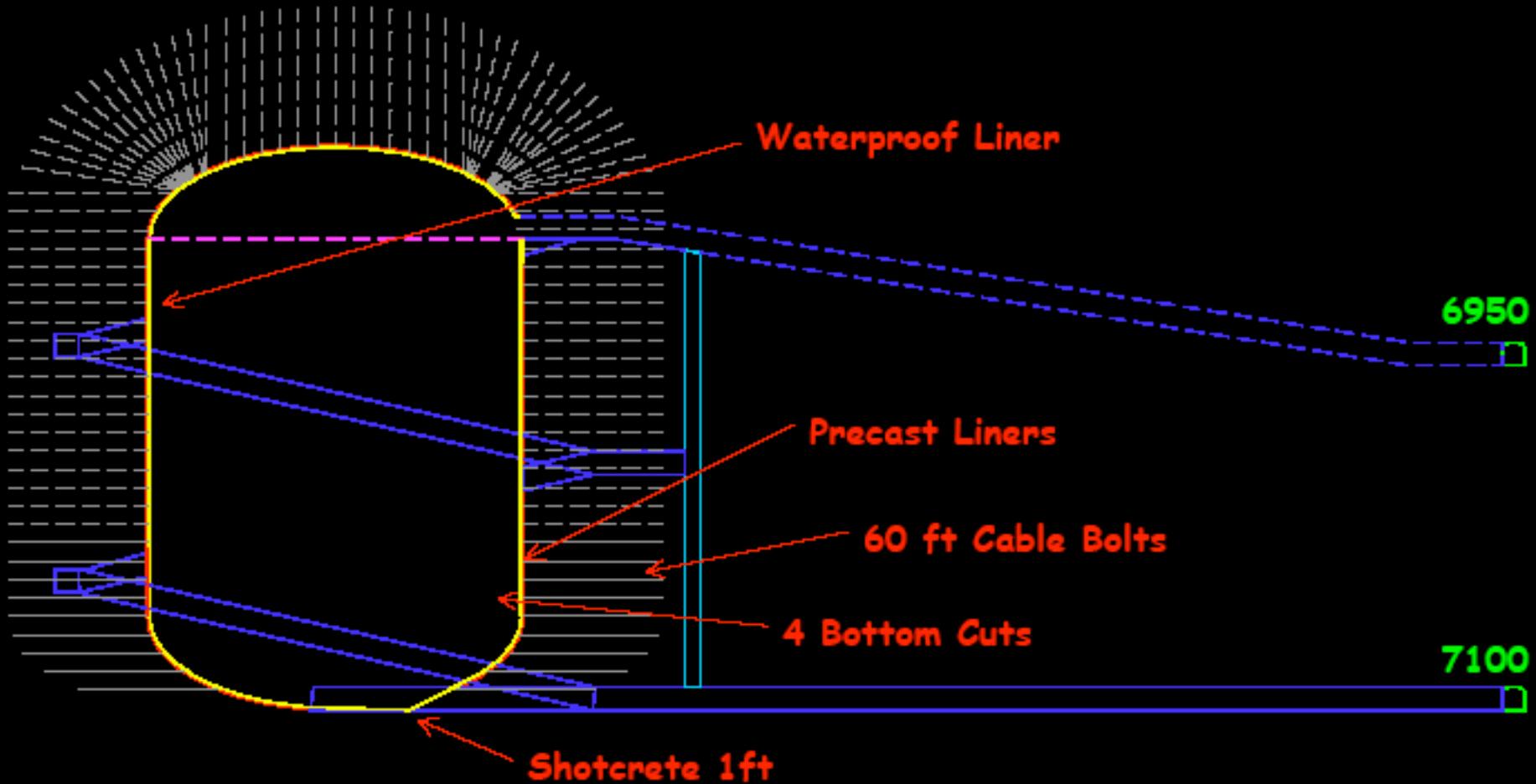


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✓ Estimated Timeline

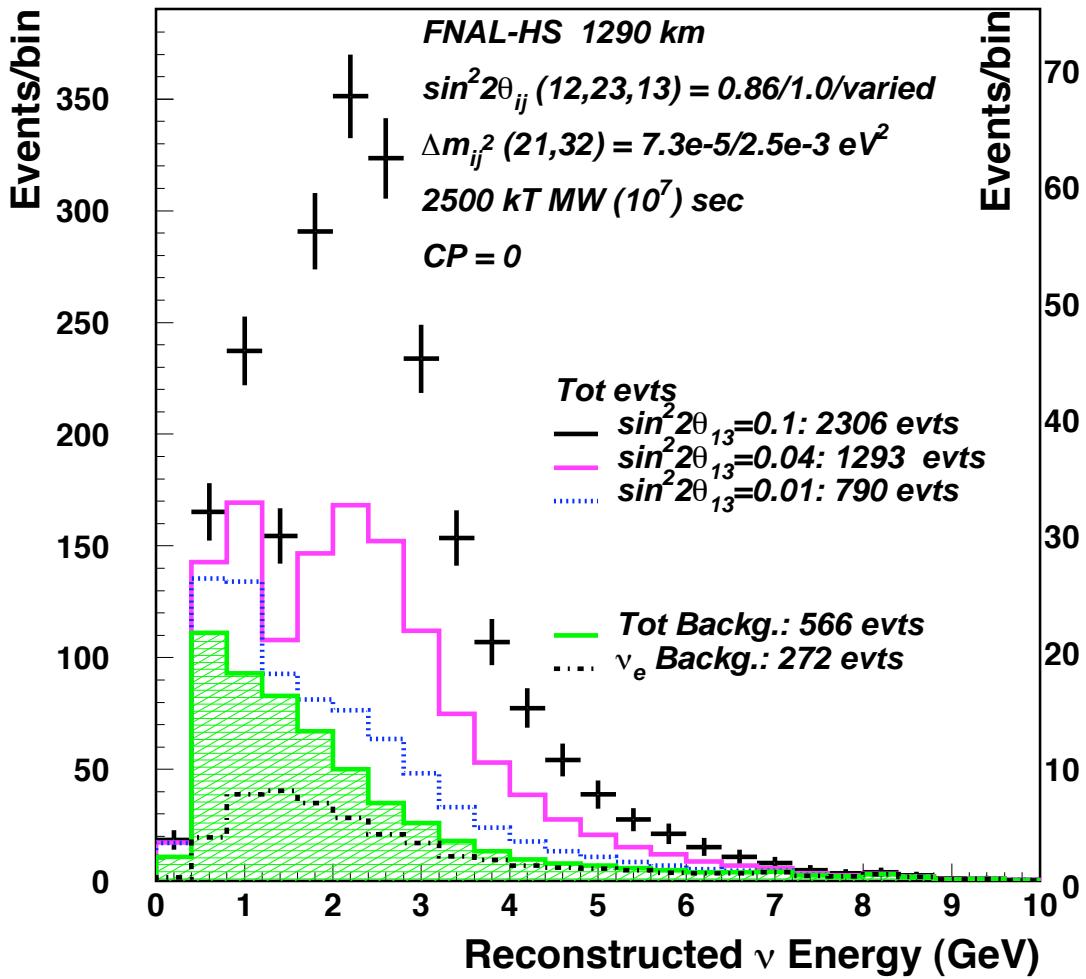
Year Four



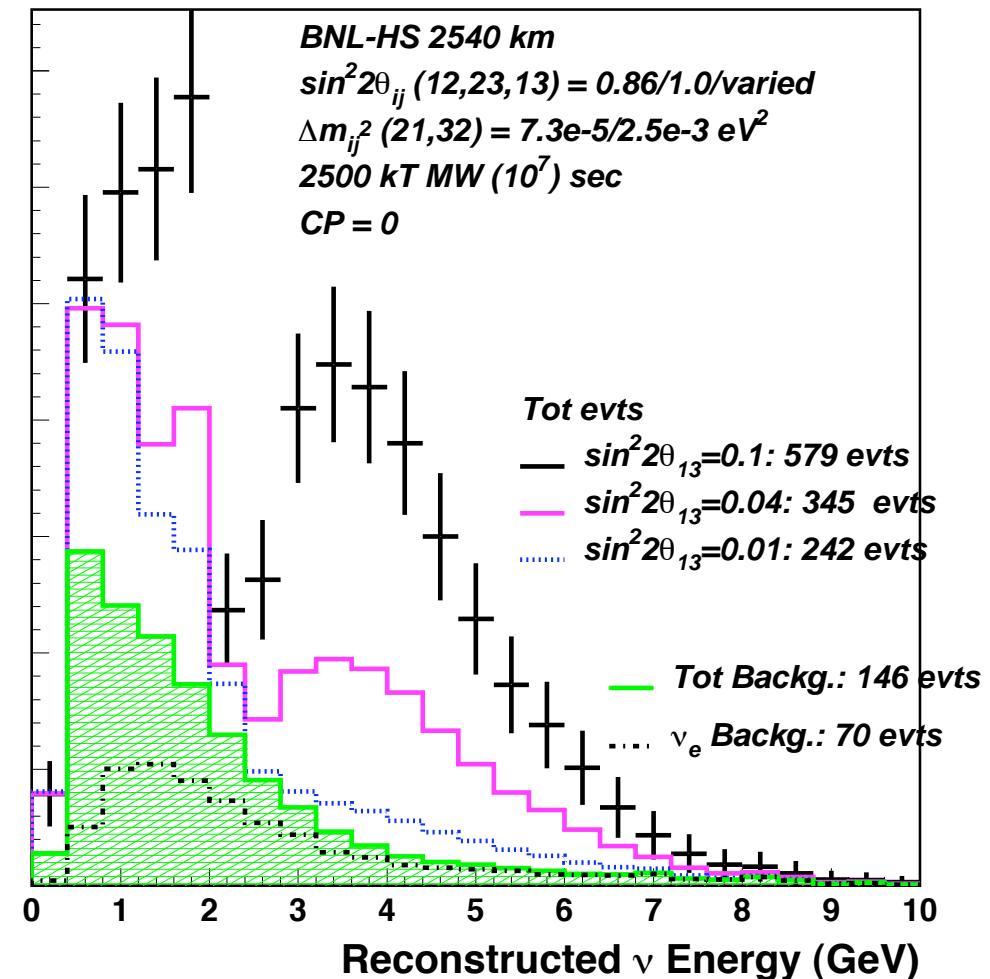
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ν_e APPEARANCE

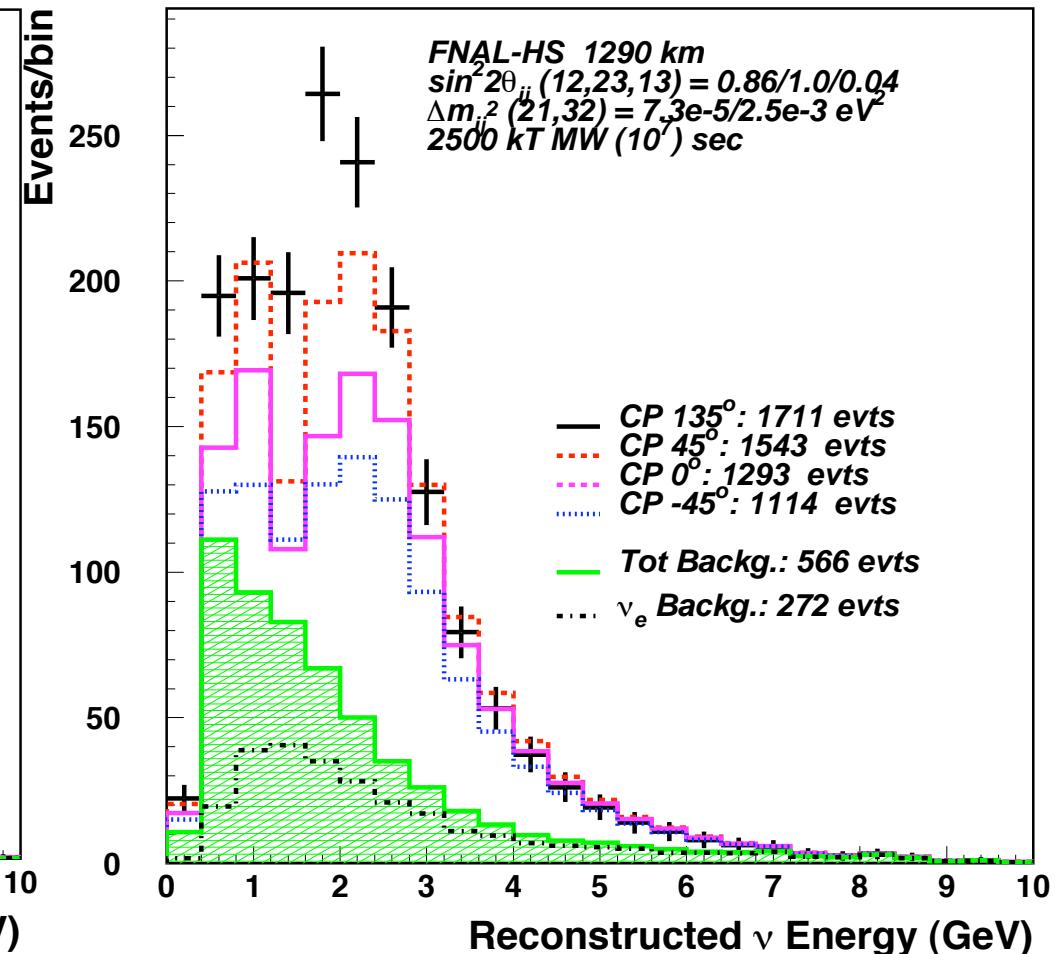
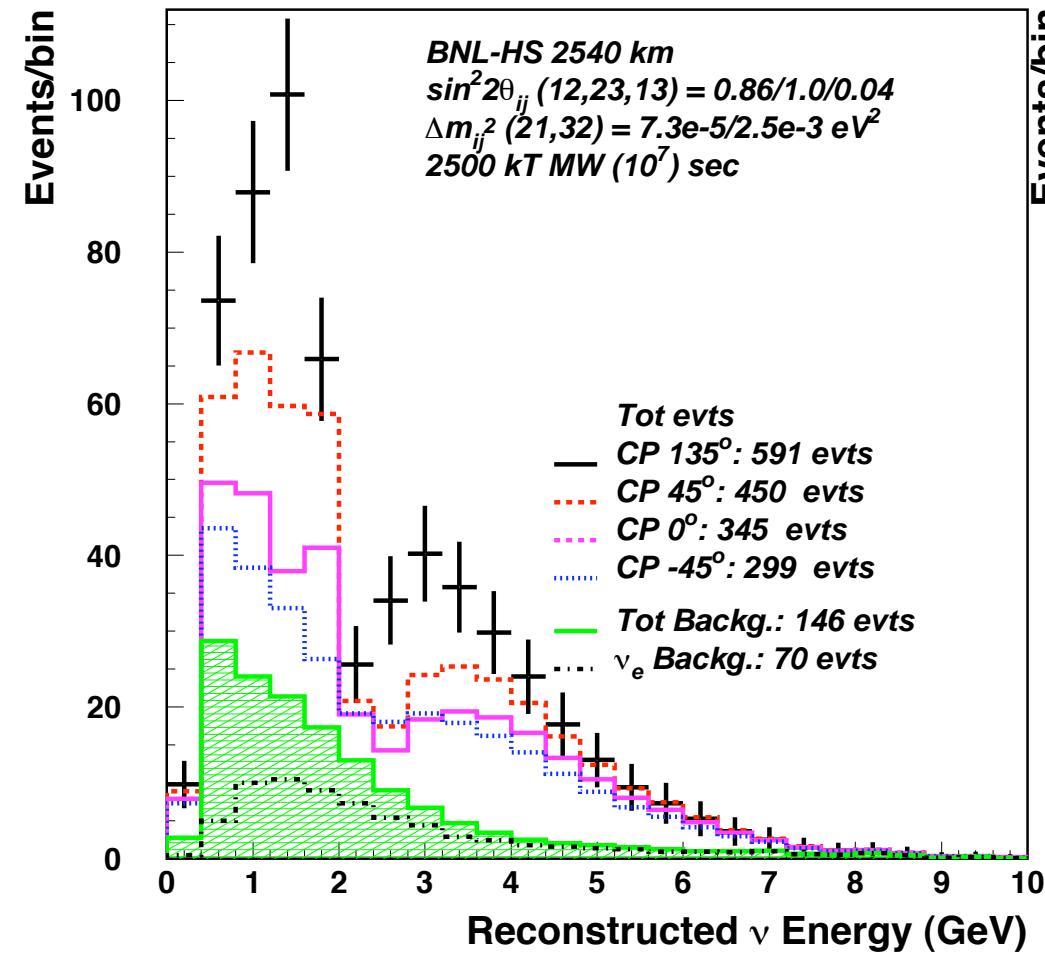


ν_e APPEARANCE



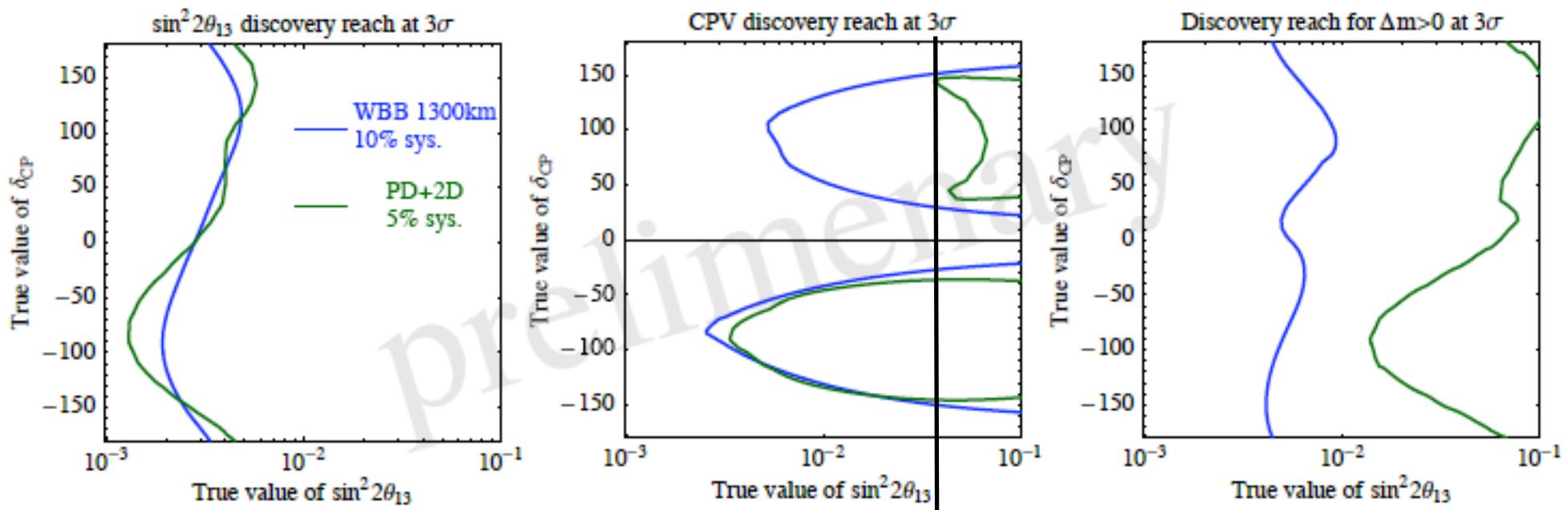
ν_e APPEARANCE

ν_e APPEARANCE



Comparison
to 1290 km to 2540 km

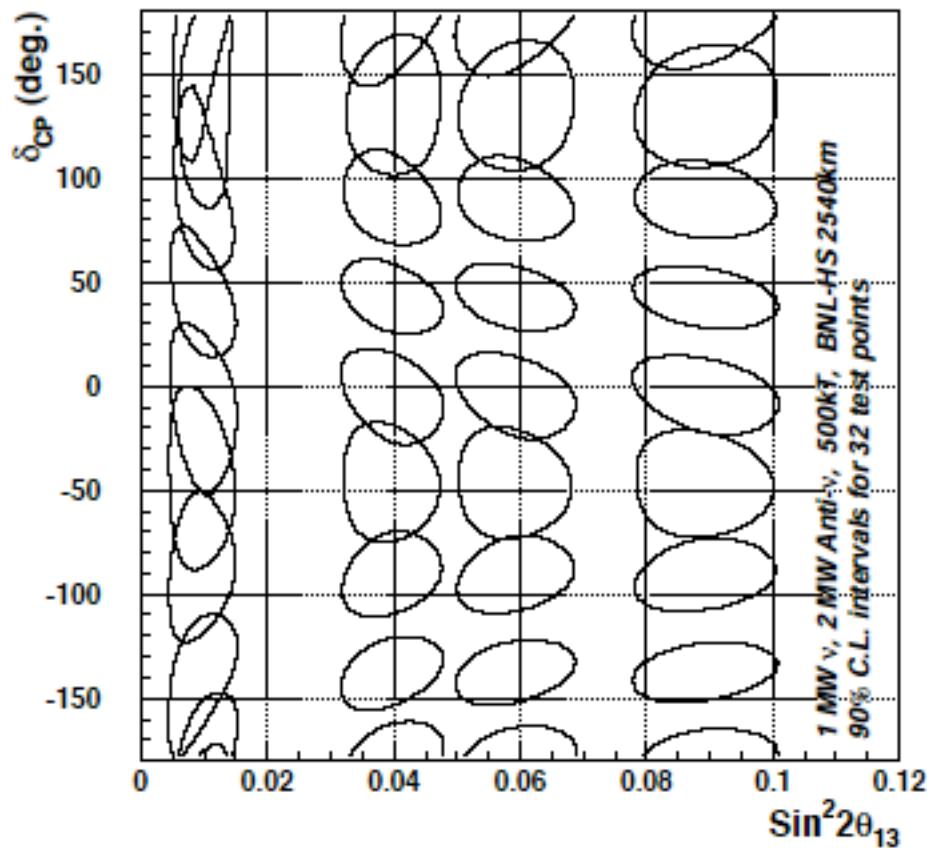
Summary



How would that picture look like with

- Liquid Argon
- 2nd peak in the OA spectrum

Regular hierarchy v and Antiv running



Regular hierarchy v and Antiv running

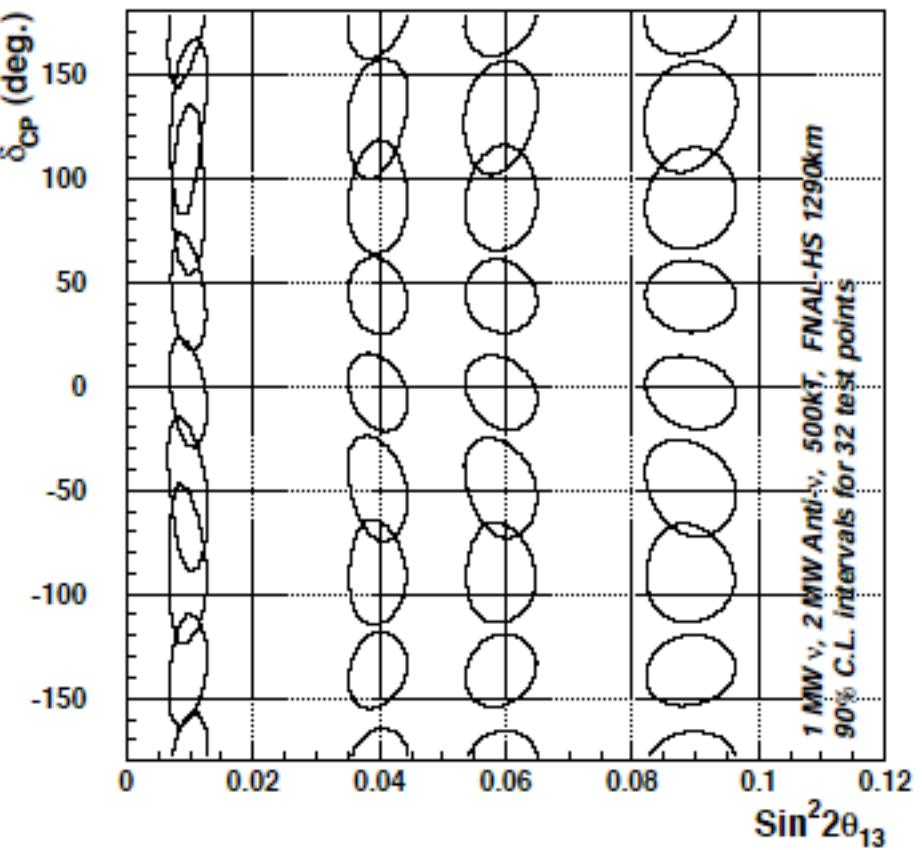


Figure 7: 90% confidence level error contours in $\sin^2 2\theta_{13}$ versus δ_{CP} for statistical and systematic errors for 32 test points. This simulation is for combining both neutrino and anti-neutrino data. Left is for BNL-HS and right is for FNAL-HS. We assume 10% systematic errors for this plot.

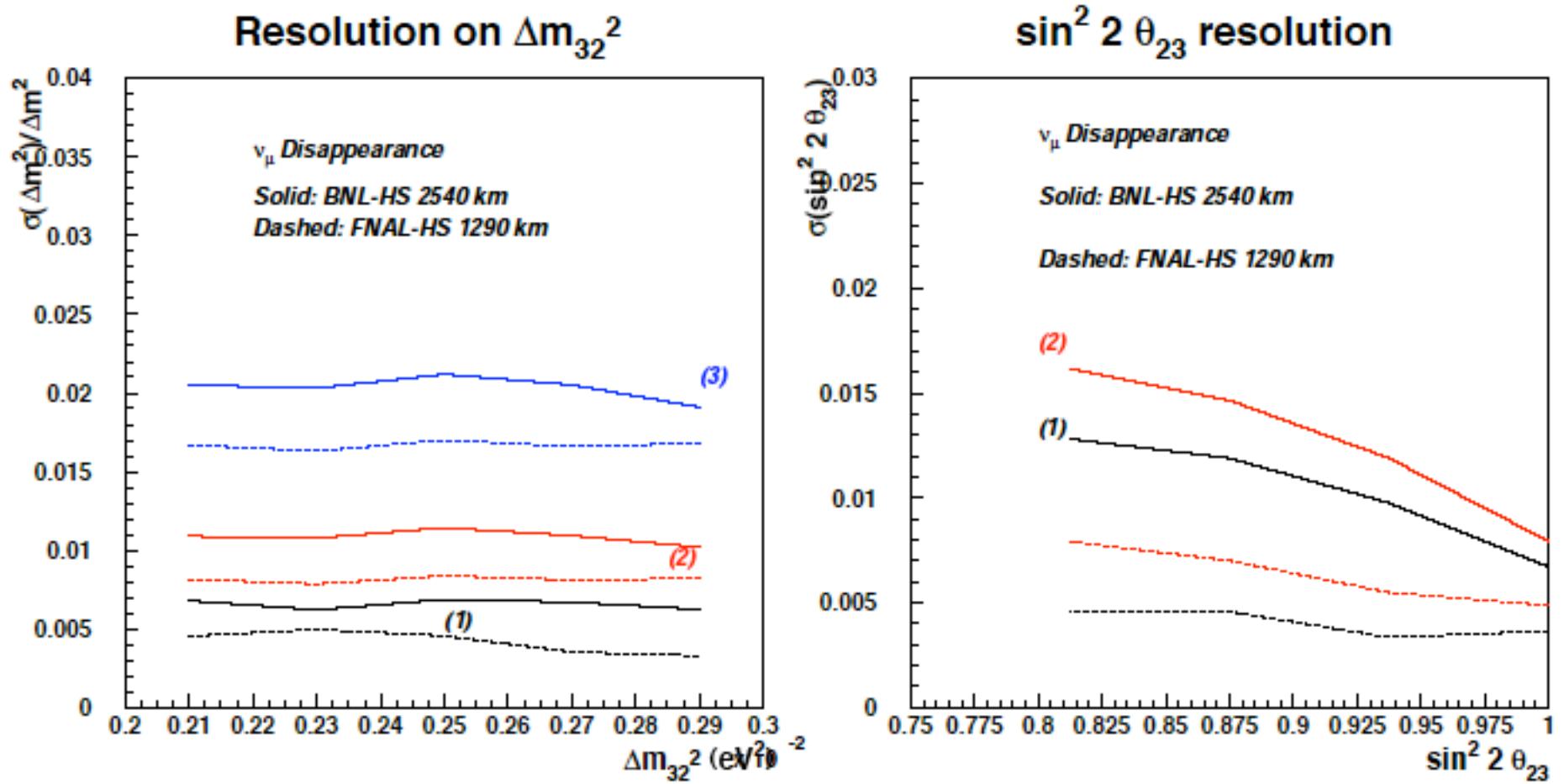


Figure 3: 1 sigma resolutions on Δm_{32}^2 (left) and $\sin^2 2\theta_{23}$ (right) expected after analysis of the oscillation spectra from Figure 2. The solid curves are for BNL-HS 2540 km baseline, and the dashed are for FNAL-HS 1290 km baseline. The curves labeled 1 and 2 correspond to statistics only and statistics and systematics, respectively (similarly for dashed curves of the same color). The curve labeled (3) on the left has an additional contribution of 1% systematic error on the global energy scale.